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The Use and Market for WOOD in the ELECTROMETALLURGICAL Industry

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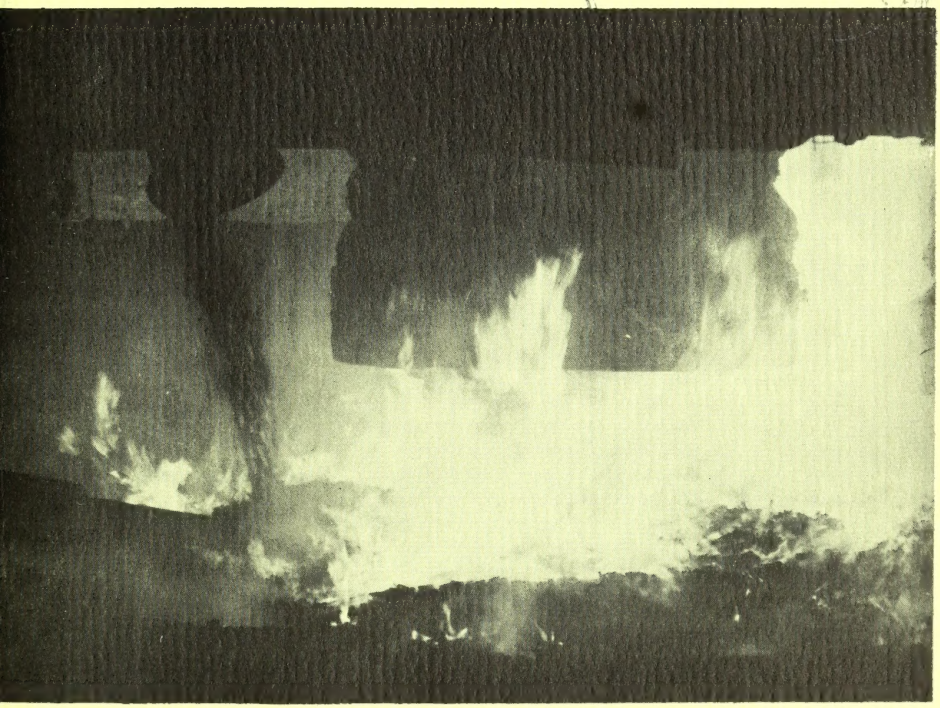

By Jeffrey L. Wartluft

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NORTHEASTERN FOREST EXPERIMENT STATION, UPPER DARBY, PA.
FOREST SERVICE, U. S. DEPARTMENT OF AGRICULTURE
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COVER PHOTO: View of a submerged-arc electric furnace as a mixture of ore and reducing agents — including wood chips — is introduced.

The Use and Market for WOOD in the ELECTROMETALLURGICAL Industry

WOOD RESIDUES, particularly large chips, play an important role in the electric smelting of certain ferro-alloys. This is a report on the characteristics and growth potential of the market for wood in the electrometallurgical industry, including a brief account of how wood is used in electrometallurgical processes, a discussion of the preferred form of wood used, a description of plant locations and factors affecting the market, and a look to the future.

The information for this report was obtained from personal and telephone contacts with purchasing agents, metallurgists, plant managers, equipment manufacturers, government agencies, and university professors of metallurgy. From these contacts, a list was made of all known electrometallurgical firms in the United States that use wood. Plants in the upper Ohio River Valley were visited in early 1969, and all firms were interviewed by telephone in 1970.

HOW WOOD IS USED IN ELECTRIC SMELTING

In smelting processes (fig. 1), which extract or reduce metals from their ores, wood is used as a reductant. In this paper wood is referred to as a woody reductant to distinguish it from the other reductants, coal and coke. Electric smelting is a continuous process in which a mixture of ore and reducing agents — wood chips, coke, and coal — is added into the top of an electric furnace at regular intervals (cover photo). Carbon electrodes submerged in the mix melt the material, which is periodically tapped from the bottom of the furnace.

The basic chemistry involved is the combining of oxygen in the ore with carbon from the reducing agents, thereby setting the metallic portion of the ore free. The carbon and oxygen form carbon monoxide, which escapes from the furnace as gas.

Wood constitutes 10 to 75 percent by weight of the furnace mix. This proportion varies according to the origin and particle

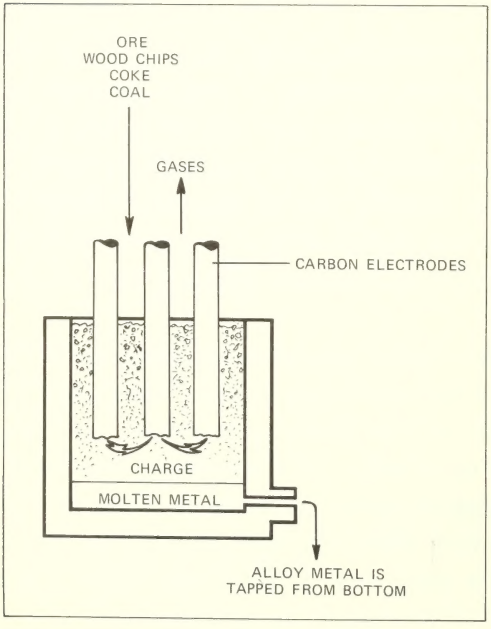


Figure 1. — Diagram of a submerged-arc electric furnace. The ore, wood chips, coke and coal — introduced at the top of the furnace — are mixed in varying proportions to produce the alloy desired.

sizes of the ore, the type and quality of the alloy being produced, the furnace design, the moisture content and size of the wood particles, and the artistry of the electric smelter. The metallurgy of electric smelting depends upon art as well as upon science. Hence the use of wood chips appears to reflect the individual metallurgist's or smelter's convictions as well as technological and economic considerations.

Although wood chips provide some of the carbon for chemical reaction, their primary usefulness in the charge is due to their bulk. Some of the reasons metallurgists cite for the use of wood in the charge are:

- To provide a large surface area for chemical reaction to take place more completely and at improved rates.
- To maintain a porous charge, thereby promoting gentle and uniform — instead of violent — gas venting.
- To help regulate smelting temperatures.
- To keep the furnace burning smoothly on top.
- To reduce conductivity.
- To promote deep electrode penetration.
- To prevent bridging, crusting, and agglomeration of the mix.
- To make possible the smelting of finely divided raw materials without sintering.
- To reduce dust, metal vapor, and heat loss; and as a result to improve working conditions near the furnace.

THE FORMS OF WOOD USED

Throughout the United States the electrometallurgical industry uses wood from many sources: slabs, edgings, and trimmings from sawmills; trimmings from pallet, flooring, and furniture plants; roundwood; logging slash; bark; paper chips; oversize paper chip screenings; and, in the West, hogged fuel. Bark, paper chips, oversize paper chip screenings, and hogged fuel are used as is. Other sources are reduced in size by chippers.

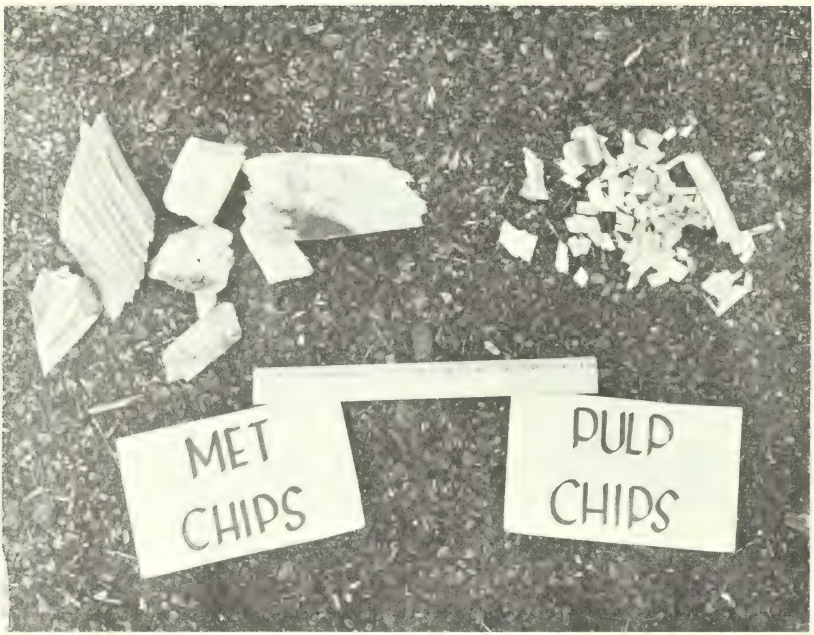


Figure 2. — A comparison of metallurgical chips and pulp chips.

The form of wood best suited for electric smelting is the metallurgical or met chip. The met chip is several times larger than the more familiar pulp chip (fig. 2). These chips are produced by specially built metallurgical chippers designed for big loads and for cutting large chips.

AMOUNT AND LOCATION OF WOOD USED

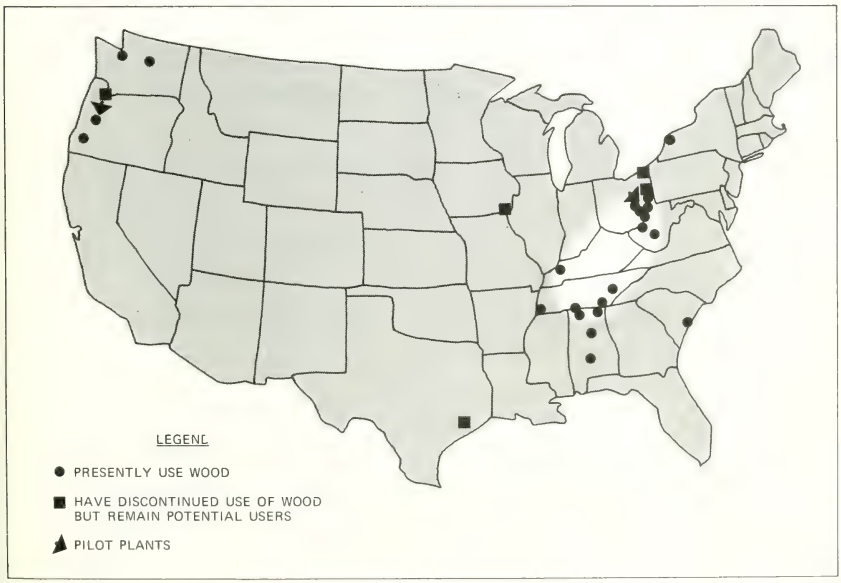
The electrometallurgical industry consumes about 796,000 tons (green weight) of wood annually — enough to operate a 500-ton-per-day pulpmill for 1 year. Fifty-nine percent, 480,000 tons, is consumed by plants in the Ohio and Tennessee River Valleys (fig. 3). Consumption varies from 6,000 tons to 78,000 tons per plant per year. Average annual consumption per plant is 36,000 tons.

Bark residues represent about 5.3 percent of the total amount of woody reductants consumed. Of these bark residues, 30,400 green tons are hardwood bark and 12,000 green tons are pine bark.

FACTORS AFFECTING WOOD PURCHASES

The general conditions that govern the purchasing of wood for the industry concentrated in the Ohio and Tennessee River Valleys do not necessarily hold true for plants scattered in other parts of the country. Consider the market for wood in terms of the met chip only, as it is the best woody reductant found today.

Figure 3. — The location of electrometallurgical plants in the United States that use wood chips. The study was concentrated in the Ohio and Tennessee Valley region (unshaded area).



Supply and Demand

The supply of met chips is not adequate in certain areas. In fact, the one plant that discontinued using wood in this region (fig. 3) did so not because wood residues were not available, but because the proper type of met chip was not available. Situations like this arise because: (1) the demand for wood in electric smelting is concentrated in certain areas; (2) other wood buyers such as pulpmills, particleboard plants, and charcoal producers seek similar raw materials in large quantities to meet their requirements; and (3) winter and wet weather hamper logging operations, which in turn affect the availability of all forest products.

The demand for met chips at any one plant, though relatively constant from year to year, can vary as much as 600 percent from month to month. This fluctuation is caused by changes in the production schedule. Each alloy requires a different amount of met chips per unit of production; so any change in the type of alloy being produced is likely to cause up to a sixfold change in the amount of wood needed.

The purchaser of met chips has to deal with these problems of fluctuating demand on the one hand, and changing levels of supply on the other. Some of the methods used in coping with these problems involve inventory manipulation, new sources of raw material, and long-term contracts.

A large inventory is necessary to balance out the changing levels of supply and demand. At the plants in the study area, enough material is maintained to enable unhampered smelting for 2 weeks to 2 months.

New sources of met chips are being drawn upon. The source with most potential is roundwood. Firms in the Ohio Valley are purchasing increasing amounts of roundwood, storing it, and chipping it as needed in metallurgical chippers installed at the plant site (fig. 4). Several of these chippers have been sold as mobile units to loggers, who process logging slash with them. At present two plants obtain 50 percent or more of their wood requirements from roundwood.

Another way of obtaining new sources is to extend the buying

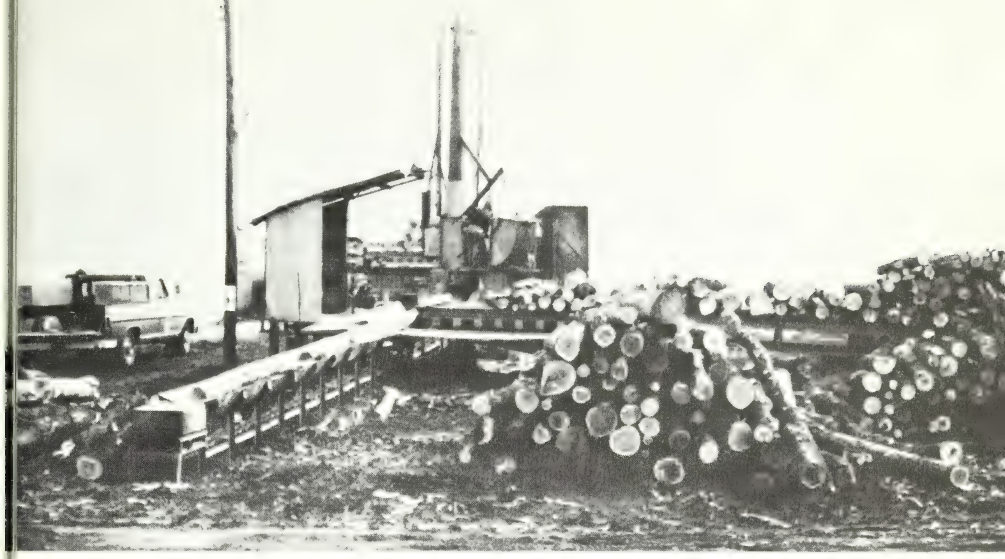


Figure 4. — A metallurgical chipper and roundwood storage.

radius. Most woody reductants are purchased within a 100-mile radius. However, when wood is scarce, metallurgical firms go as far as 200 miles in search of adequate supplies.

Several metallurgical firms have adopted long-term contracts to insure a steady supply of met chips. These contracts may call for the entire production of chipped residues from wood-processing plants for 2 or more years. And they stipulate approximate delivery rates. An added incentive is provided by bonuses given for chips in excess of the delivery rate.

More prevalent than the relatively new long-term contracts are monthly or quarterly purchase orders. Firms seeking to minimize capital tied up in stockpiles use these for flexibility in meeting changing monthly wood requirements. However, forest-products firms are reluctant to produce for these fluctuating markets.

Specifications

Specifications for woody reductants can be expressed only in generalizations. They differ from place to place because of the kind of material available, the type of equipment used in

handling these materials, and the requirements of a particular metallurgist.

According to the companies asked, the most important specification is for particle size. In the Ohio and Tennessee River Valleys, specifications on particle sizes range from 2.5 inches square by 0.5 inch thick to 8 inches square by 1 inch thick. Particles larger than these, as well as some very stringy hardwood barks, are limited primarily by the plant's materials-handling equipment. Small particles, including sawdust, generally are of no benefit because they burn up too fast in the furnace.

Woody reductants should be free of foreign material, because it imparts impurities to the alloys being produced. Because barks frequently carry dirt and mud, they are also undesirable. However, 16 of 22 United States plants do accept certain proportions of bark in their requirements for woody reductants. For instance, several plants accept wood chips from unbarked roundwood, but not from unbarked slabs and edgings because they have a higher proportion of bark.

The specifications on moisture content reflect the conflict between the art of electric smelting and economics. Most ferro-alloy plants prefer green oven-dry material because it works deeper into the furnace before burning up. However, others are more concerned about the extra expense of transporting the water and driving it off in the furnace; so they prefer dry material. To assure a more uniform moisture content in the woody reductant portion of the furnace mix, some plants blend the chips they receive from different sources.

Wood used in ferro-alloy manufacture must be free of decay.

In locations where both hardwood and softwood residues are available, hardwoods are preferred because they last longer in the furnace.

Roundwood specifications are determined by the size of log that can be handled in the metallurgical chippers. Larger chippers can handle logs up to 22 inch maximum diameter; but specifications call for 16- to 18-inch logs to take care of crook, swell, knots, and occasional oversize logs.

Prices

All wood residues and roundwood are bought by weight. The average delivered price of met chips per green ton in the study area is $8.50, with a range of $6.50 to $10.00. Roundwood costs approximately $2.00 a ton less than chips. And bark is bought at or slightly above the cost of transportation.

Transport

Most metallurgical plants prefer delivery of wood by truck. Trucking allows more flexibility in the timing and location of deliveries. Dump-trucks are used to haul most of the chipped wood. However, a recent innovation in handling is the installation of hydraulic dumpers (fig. 5) at several plants. These allow

Figure 5. — A hydraulic dumper; met chip pile in background.

the larger chip vans to more efficiently haul and dump material. Rail and barge shipments are used to a lesser extent.

OUTLOOK FOR FUTURE WOOD USE

Changes in the volume consumed, forms of, and sources of woody reductants for metallurgical purposes can be expected in the future.

Indications are that the volume of wood used in electric smelting in the future will increase. The three principal markets for ferro-alloys — alloy steel, aluminum, and silicone industries — are growing. The average increase in production of alloy steel over the past 6 years has been 6 percent annually (calculated from figures on alloy steel production supplied by the American Iron and Steel Institute, Washington, D. C.) Silicon alloys, which consume the greatest volume of met chips per unit of production, are used by the rapidly growing aluminum and silicone industries.

Changes in the form of wood used in electric smelting will probably occur in the future. Large modern furnaces need precise and uniform raw-material inputs for efficient computerized control. And since met chippers provide the most suitable material available, the trend in their use should continue to rise. This means that more and more wood residues, roundwood, and logging slash will be used to help satisfy the increasing demand for high-quality woody reductants in large quantities.

Bark is now being used, but use of bark relies on favorable economics rather than on its record of performance. The use of bark in electric smelting is still considered as experimental. Future technological advances could conceivably make bark more appropriate for this use.

In the past, experiments with sawdust compressed into briquettes for electric smelting have been unsuccessful. However, interest has been renewed; and sawdust-briquetting trials have been started at the University of Ohio, in Athens.

The most apparent and meaningful trend to be expected in future purchasing practices for wood is the changeover from

purchase orders to long-term contracts. Their more widespread use would provide a more stable and attractive market for suppliers of metallurgical chips.

APPENDIX

LIST OF U. S. ELECTROMETALLURGICAL PLANTS USING WOOD CHIPS

Company	*Location*
Airco Alloys	Niagara Falls, New York
Airco Alloys	Charleston, South Carolina
Airco Alloys	Calvert City, Kentucky
Calumet & Hecla, Inc.	Selma, Alabama
Chromium Mining & Smelting Co.	Woodstock, Tennessee
Foote Mineral Co.	Graham, West Virginia
Foote Mineral Co.	Wenatchee, Washington
Hanna Nickel Smelting Co.	Riddle, Oregon
Interlake Steel Corp.	Beverly, Ohio
National Metallurgical Corp.	Springfield, Oregon
Ohio Ferro-Alloys	Powhatan Point, Ohio
Ohio Ferro-Alloys	Brilliant, Ohio
Ohio Ferro-Alloys	Philo, Ohio
Ohio Ferro-Alloys	Tacoma, Washington
Reynolds Aluminum	Sheffield, Alabama
Roane Electric Furnace	Rockwood, Tennessee
Tennessee Alloys	Bridgeport, Alabama
Tennessee Metallurgical Corp.	Jasper, Tennessee
Union Carbide Corp.	Alloy, West Virginia
Union Carbide Corp.	Marietta, Ohio
Union Carbide Corp.	Sheffield, Alabama
Woodward Iron Co.	Woodward, Alabama

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by Gerald M. Aubertin

Nature and Extent of MACROPORES IN FOREST SOILS and their Influence on Subsurface Water Movement

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Nature and Extent of MACROPORES IN FOREST SOILS and their Influence on Subsurface Water Movement

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Macropores

RAIN, falling on a sloping forested soil, may enter the soil quickly and move considerable distances through the soil by way of macropores. A macropore is a large pore, cavity, passageway, channel, tunnel, or void in the soil, through which water usually drains by gravity.

Large quantities of water can move through the soil by way of these macropores—without appreciably wetting the soil mass. This phenomenon complicates the study and management of forested watersheds.

A series of studies was undertaken to provide information about the nature, extent, and influence of macropores, as an aid to future studies and management of forest soils. This is a report on those studies.

Background

Macropores occur extensively in forest soils. They serve as drainageways through otherwise impervious soils; they improve subsoil aeration; and they often serve as favorable sites for root growth.

In terms of macropores, most forest soils are extremely heterogeneous, in both vertical and horizontal directions; and the macropores frequently are concentrated in certain horizons and in particular areas of the forest.

Most macropores develop from old root channels or from burrows and tunnels made by insects, worms, or other animals. Some result from structural pores and cracks in the soil. Our studies dealt mainly with macropores resulting from biotic activity.

ROOT CHANNELS

Root channels are formed in place by decomposition of roots. The channels are first filled or partially filled with porous organic material derived from the roots themselves. Depending on their location with respect to the forest floor surface, additional organic residues from the litter horizons may be added to the channels.

As soil material moves into the channels, the mixture comes to resemble the A1 horizon. Eventually, as the organic matter is oxidized, the contained materials take on the appearance of an A2 horizon. During normal processes of soil development, clay particles become dispersed and move into the channels and are deposited as clay skins on the sides of the channels. This layered material is different in color, depending on its source in the profile, its age, the time of filling, and the conditions of aging.

The physical entrance and expansion of a root in the soil compresses the soil adjacent to it and locally changes the soil's porosity and bulk density. As a result, the percent of pore space near the root channel-soil boundary is lower than that a distance from the root's former influences *(Blevins 1967)*. This is accompanied by a shift of pore-size distribution toward the smaller capillary-size pores. In addition, a higher percentage of clay and mineral grains oriented tangent to the roots' surface is to be found adjacent to the root-soil interface than in the soil mass. These factors, along with the residues remaining from organic decomposition, promote a relatively stable conduit for the rapid conductance of free water, air movement, and new root growth.

Different tree species have different types of root systems. Thus, as the roots decay, they leave different types of root channels. Macropores resulting from the decay of plant roots are usually tubular and dendritic, and they range widely in diameter *(Johnson et. al. 1960)*. The roots of some plants leave a thick, tough, resistant bark lining around the root channels. Others tend to leave scale-like bark, which readily breaks apart. As far as I know, no one has yet undertaken a comprehensive study of the nature of root bark and its persistence in the soil.

The root channels within the forest floor form a network of

relatively large, continuous, interconnected, open or partially filled channels that serve as pathways for the rapid movement of free water into and through the forest soil profiles. Due to variation in the vertical extent of the channels, after precipitation the lower boundary of the wetted zone is often extremely irregular. Water may thus move downward to the water table through these channels or move laterally through the soil mass, which, in part, remains unwetted *(Lutz and Chandler 1946)*. In fine-textured soils, the root channels from deep-rooted tree species favor vertical drainage while those from species having long lateral roots favor lateral subsurface water movement.

Soil texture seems to affect the persistence of old root channels. In coarse-textured soils, persistent channels are not normally common. In fine-textured soils, old root channels are abundant and persist for a long time. In coarse-textured soils, "sand pipes" — thought to be the remains of old root channels, now filled with coarse whitish sand — can often be observed. These "sand pipes" have been observed to conduct a substantial amount of water.

Root channels can be numerous. For example, in a hardwood site in southeastern Ohio, over 4,000 vertical root channels were found per acre *(Gaiser 1952)*. Although most were partially filled, they were relatively permeable and served as a network of interconnected channels to freely move water through the forest soil profile. Where shortleaf pine has been cut in the Southeast and the roots have had time to decay, open or partially filled root channels, several inches in diameter and 4 or more feet deep, are found *(Kittredge 1948)*.

ANIMAL PASSAGEWAYS

Insects, worms, and burrowing animals also form macropores in forest floors. Their burrowing activities promote good structure, good aeration, and good penetration of water. In addition, their tunnels often provide avenues for the growth and development of plant roots into and through tight layers of soil.

Earthworms *(Lumbricidae)* are the most conspicuous group of animals in most forested soils. Their activity is usually greatest in the A horizons, where they are largely responsible for the

soil's porous nature. In all profiles of a forested Bellefontaine silt loam soil in Wisconsin, regardless of the resistant nature of the B horizons, earthworms and their burrows were found in the C horizons at depths of 3 to 3½ feet *(Scully 1942)*. The burrows were fairly perpendicular, deviating where rocks blocked the path. Nielsen and Hole *(1964)* found earthworm burrows having an average diameter of 5/16 inch were spaced at about 6-inch intervals and extended nearly vertically to a depth of 3 to 6 feet. They said that earthworms are responsible for making tubular extensions of the A1 down into the A2 horizon, which increases the interface of these two horizons and augments the permeability of soil to water and tree roots.

Cicada *(Magicicada septendecim)* burrows are also abundant in soil. On 30-meter quadrats sampled at random, Scully *(1942)* found an average of 14 cicada mounds per square meter, with open burrows extending almost perpendicular to varying depths.

Small burrowing animals are abundant in most forests and have a pronounced influence on soil conditions. Ground squirrels, moles, mice, and shrews often produce a labyrinth of interconnecting tunnels that allow ready penetration of air and water and facilitate their distribution within the soil body *(Lutz and Chandler 1946)*. Hamilton *(1940)* indicated that the looseness of the surface layers in many forests in the Northeastern States is due in part to the scores of burrows made by mice and shrews. The magnitude of animal burrows can be very great: Eadie *(1939)* found 220 surface tunnels of the hairy-tailed mole *(Parascalops breweri)* exposed along a newly cut road bank within a distance of 492 feet, making an average of one tunnel every 2.2 feet. These surface tunnels formed an irregular branching network, with main surface tunnels often extending beside or under some surface structure for 100 yards or more.

NONBIOTIC MACROPORES

Other agents, such as freezing and thawing, are also responsible for the formation of macropores in forest soils. Freezing the soil increases its porosity because the growth of ice crystals causes displacement and bulking of the soil *(Krumbach and*

White 1964). These pores may persist under undisturbed forest floor conditions and be preserved by the covering of litter *(Auten 1933).*

Cavities formed by leaching and dissolution of pebbles of limestone or dolomite have been found to form as much as 10 percent of the B22 horizon of Howard gravelly loam in Bradford County, Pennsylvania *(Denny and Lyford 1963).*

The Study

SITE

The study site was 1.2 miles north of Dover Dam in Tuscarawas County, Ohio, on land made available through cooperation of the Muskingum Watershed Conservancy District. A moderately steep south-southwest slope, covered by a mixed deciduous hardwood forest, was selected for study. Dominant trees were primarily white oak, beech, and hickory; diameters averaged about 18 to 24 inches. Six study locations were used. The soil type at the upper location, approximately 150 feet from the ridge, was a Dekalb sandy loam; the soil types at the five lower locations — on a line parallel to the slope — were characterized as variants of Clymer silt loam. The lowermost location was near midslope, approximately 500 feet from the ridge. The slope ranged from about 20 percent near midslope to about 25 percent at the upper location.

METHODS

Outflow Pits

Observation pits, approximately 4 feet deep and extending approximately 10 feet across the slope, were dug at the uppermost and lowermost locations. The sandy loam here was underlain by a layer of moderate to coarse sand at about 40 to 45 inches. The silt loam graded at about 36 inches into a silty clay, which graded into a clay at about 44 inches.

Artificial rain, containing fluoresceine dye, was applied to the undisturbed surface of the forest floor immediately upslope from the pit faces at the rate of 1 inch per hour. An area 16

feet in diameter was wetted above each pit. Time and location of outflow from each pit face were recorded. Volume of outflow was measured from a selected number of outflow spots.

Hydraulic Conductivity

For evaluating hydraulic conductivity, a specially designed core sampler *(Aubertin 1969)* was used to obtain a large number of relatively undisturbed soil samples 6-inches in diameter and 3, 6, 9, 12, 15, and 18 inches deep. These samples included small stones, roots, old root channels, animal passageways, and other macropores in their natural state.

A sufficiently large number of samples was collected so that at each of the six locations at least 20 relatively undisturbed samples were obtained for the 0-6-, 6-12-, and 12-18-inch depths, and at least 10 similar qualitative samples were obtained for the 0-3-, 3-6-, 6-9-, 9-12-, 12-15-, 15-18-, 0-12-, and 0-18-inch depths.

The samples were placed in water and allowed to soak for about 24 hours before establishment of a constant head of about 15mm. via the overflow method *(Klute 1965)*. As soon as the constant head was established, outflow measurements were begun and were recorded every 2 to 5 minutes throughout a total lapsed time of 100 minutes. Hydraulic-conductivity values were calculated, then plotted against lapsed time on semilogarithmic paper.

Upon completion of the outflow measurements, but without allowing air to enter the sample, a 0.1-percent malachite green dye solution was passed through the sample. The amount of dye solution used per sample varied according to the rate of flow. This dye solution stained the major flow channels, making them readily visible when the samples were dissected. In addition, dye staining along the sample-cylinder wall interface revealed if and where flow occurred between the sample and the cylinder wall.

The samples were allowed to drain approximately 24 to 48 hours, then were dissected. Data from samples exhibiting evidence of sample-wall flow were not included in the analyses. As dissection proceeded, qualitative and semiquantitative remarks were noted on flow passageways, old root channels, animal passageways, macropores, and evidence of soil disturbance such as filled root channels or animal passageways, in an attempt to correlate

their presence with the hydraulic-conductivity value obtained for each given core.

Block Study

To further evaluate the nature of the macropores *in situ,* a large free-standing block of soil, 8 feet wide by 20 feet long by 6 feet deep, was exposed by trenching around the four sides with a backhoe. This block corresponded to the lower part of the active portion of a previous subsurface stormflow plot *(Whipkey 1965).* The downslope face (front) of the block was coincident with the outflow face of the former plot.

After the block had been trimmed and shaped by hand, all four sides were gridded into 6-x-6-inch squares, characterized, and sampled; and the soil horizons were mapped. All major features such as roots, stones, old open root channels, old filled root channels, filled and unfilled animal burrows, evidence of taproots, worm and other macro-organism passageways, and structural cracks were mapped to scale for the front, back, and one side. Unfortunately, because of wet weather, a portion of one side sloughed down before its features could be mapped.

After the external features had been mapped, the front or downslope and the back or upslope portions of the block were systematically dissected by carefully removing 6-inch cubes of soil one at a time. All major internal features, such as listed above for the external faces, were carefully traced and mapped on three-dimensional drawings.

A powerful industrial vacuum cleaner with a hurricane nozzle was used for cleaning up the loose material from the faces and for removing the loosened soil from the cube being dissected. The soil was loosened most efficiently with the point of a stiff knife blade, then was removed with the vacuum nozzle. A curved linoleum knife was found to work very well in loosening the soil with a minimum of disturbance to the roots and root channels. With careful work, very few roots were cut or removed, and it was possible to easily trace the roots from one point to another. Root channels were also easy to trace by using this method of soil removal, but because of their fragile nature many of them

were obliterated as the soil was removed. Consequently all root channels and other open channels had to be continually mapped as the cube was dissected.

Results and Discussion

OUTFLOW PITS

A comparison of the faces of the observation pits showed marked differences in the presence of biotic macropores. Outflows from the pit faces also differed markedly in timing, rate, and distribution.

Qualitative observations showed a substantially greater number of old root channels in the finer textured soils. In these soils the root channels were distinct, well-preserved, generally open or only partially filled, and were ramified throughout the upper portion of the soil profile, with many extending below the 4-foot depth of the pit. Evidence of old taproots was clearly visible. Many old root channels were lined with persistent root bark. The mineral soil immediately surrounding the channel in the lower B horizons frequently had a pronounced gray color, indicating a gleyed condition.

These old root channels formed a network of pipes through the soil profile. Though we did not specifically study the areas immediately surrounding the root channels, evidence indicates that the dense zone of high clay content, and oriented particles reinforced by residues from decomposition of organic matter, were practically impervious to penetration by water.

Artificial wetting of the forest floor immediately upslope from the pit face revealed to a limited extent the influence root channels have on rapid subsurface movement of water in medium to moderately fine textured forested soil. In all cases numerous outflow sites were present in the pit face, many flowing pipe-like or faucet-like. However, there was little, if any, evidence that the soil mass proper was wetting up.

In a typical instance, applying artificial rain at the rate of 1 inch per hour to the finer textured soil (having approximately

20 percent initial moisture by weight) resulted in dye seepage coming up from the heavy, mottled clay pit floor, 18 linear feet from the center of the wetted area and 48 inches below the soil surface, within 15 minutes after starting to wet the area. Within 18 minutes after the start of the rainfall 3 additional small root channels located in the clay zone at a depth of 44 to 48 inches began seeping. In general, a depth/time-of-wetting relationship appeared to exist, and the deeper positions seeped first.

Sixteen positions (12 definitely old root channels, 1 from around a stone, 1 from an unidentified type of channel filled with dark spongy material, and 2 of undetermined nature) were seeping from the pit face within 1 hour. Seepage rates were generally moderate to rapid; four old root channels flowed pipe- or faucet-like. After continued application of artificial rain, 26 positions were seeping at the end of 2 hours. The soil mass proper did not appear to be wetting up, although at the end of 2 hours some evidence was noted that the soil surrounding some of the channels was becoming wet.

In another instance, from an approximately ¼-inch-diameter old root channel, partially lined with bark, at a depth of 23 inches, outflow began approximately 9 minutes after wetting of the surface was begun. This particular root channel yielded an outflow volume of 1,127 ml./min., measured between the 10th and 11th minutes after start of the rainfall. In all cases at least one and usually several old root channels flowed pipe- or faucet-like from the finer textured silt loam soil.

At one location in the silt loam soil, in addition to outflow from the immediate pit face under observation, flow was observed coming from channels in another pit about 30 feet obliquely downslope from the wetted area, commencing between 30 and 45 minutes after starting to wet the forest floor above the observation pit. Outflow volume, although not measured, was substantial. This points up the fact that a substantial amount of water may rapidly enter into and move a considerable distance downslope through old root channels.

The data and observations bring up an interesting question: How does the water enter into and move through the soil so

rapidly and in the quantities observed? First, the rapid movement through the soil has been demonstrated to occur through old root channels. The question of rapid entry and concentration of the rainfall has not been completely answered.

Qualitative observations have shown that the surface of undisturbed forest soils is highly porous and sponge-like. Additional observations revealed that the surface of the mineral soil is not smooth but has considerable microrelief variation. In addition, there are numerous depressions, filled with porous spongy material, which are the remains of old taproots.

Thus it appears probable that rainfall rapidly penetrates the highly porous forest floor surface, moves along the mineral surface interface, and collects in the depressions formed by decayed taproots. The water is then funnelled downward and combines with that coming from similar nearby sites through the interconnected network of channels. This subsurface water is then transmitted via paths of least resistance to the channel opening in the pit face. This may explain why overland flow seldom, if ever, occurs on sloping forest-covered soils.

This question can be raised: Does digging a pit that intersects the root channels create an artificial system? In many if not most forested areas the soil mass is honeycombed with a complex network of intricately interconnected old root channels, animal passageways, and other microvoids. Strong arguments can be advanced to support the contention that, under these conditions, the complex network is always open to the atmosphere at numerous points and that truly dead-end isolated channels, or macrovoids, are rare and of little consequence.

Studies on the sandy loam produced similar but less pronounced results. First, the number of old root channels was considerably smaller than in the finer textured soils. Second, those present did not appear to be as distinct and as well preserved. Most channels were filled or partially filled with dark sandy material. Root-bark linings were present but fewer and usually more discontinuous than those found in the finer textured soils. Although this was not studied, qualitative observations indicated a general lack of particle orientation or clay concentration near the root channels.

In the coarser textured soils, seepage was not restricted to old root channels. At approximately 40 to 44 inches in depth, the sandy layer overlying a heavier sandy clay zone wet up rather uniformly and began to seep within 35 to 45 minutes after wetting of the soil was begun. The most noticeable difference between the coarse and fine textured soils was that, in the coarse textured soil, the soil itself appeared to wet up and the initial time of outflow from the root channels did not appear to be related to the depth of the channel. Also, the volume of outflow from individual root channels was usually considerably less in the coarser textured soil than in the finer. Apparently the less-well-preserved old root channels and relatively large textural macro-voids allow the rainfall to readily enter and permeate the soil mass as a whole instead of being restricted to subsurface channels.

HYDRAULIC CONDUCTIVITY

Determining the true hydraulic conductivity of sloping forested soils is beset with a multitude of obstacles. Because of the high porosity of the surface layers, the abundance of roots, macropores, and channery fragments, hydraulic conductivity cannot be determined by means such as Bouwer's double-tube method *(1961, 1962)*. For the same reasons, attempts to obtain satisfactory and relatively undisturbed soil samples with the 3-inch Uhland sampler proved futile. Those 3-inch samples that could be obtained would not adequately represent the configuration of the old root channels, animal passageways, and other macropores found within the soil.

Consequently, a specially constructed core sampler *(Aubertin 1969)* was used to obtain a large number of 6-inch relatively undisturbed soil samples that included small stones, roots, old root channels, animal passageways, and other macropores. Though the results obtained from these samples are better than those from small samples, they still do not provide all the information needed.

However, there seems to be a close correlation between the presence of old root channels and overall conductivity, The data strongly suggest that with our forested soils, the overall conduc-

tivity is made up of two parts. The first is the hydraulic conductivity through the soil matrix itself. The second is essentially the inner-mass flow through old root channels, cracks, and macroorganism pathways. In our studies, the matrix conductivity was often found to be completely masked by inner-mass flow, which may be several hundred times more rapid.

Through-flow was found to be extremely variable in rate and magnitude for both supposedly replicated and unrelated samples. This variability was shown, by sample dissection, to be due mainly to the presence or absence of continuous old root channels and/or animal passageways that intersected both the top and bottom surfaces of the sample. A 50-fold difference between the initial through-flow rate for the slower and faster flowing samples was not at all uncommon.

Sample dissections revealed that vertical channels or passageways were absent in those samples having a low through-flow rate while those samples having high through-flow rates always had continuous vertical channels or passageways that intersected both the top and bottom surfaces of the sample. Samples exhibiting intermediate through-flow rates were found to contain varying numbers of, and usually smaller, continuous and/or discontinuous vertical channels or passageways. Our data indicated decisively that even one continuous but small old root channel that intersected both the top and bottom of the sample transmitted a tremendous volume of flow compared to that conducted through the sample matrix.

Channels or passageways that were cut by the top surface, but not by the bottom surface of the sample, normally had their upper portion dye-stained, indicating some flow, but lacked staining throughout the majority of their length. Channels or passageways that were cut by either the bottom and a side, or by the sides only, rarely showed signs of staining. Branched channels or passageways normally had staining only on those branches that were connected directly to both the top and bottom sample surfaces. Dead-end macropores, such as cicada tunnels and cavities, seldom exhibited signs of staining.

Sample dissection also revealed that flow occurred down and

around live roots. The root-soil interfaces of all roots cut by both the top and bottom of the sample were normally stained continuously throughout the full length of the root. Staining, although always continuous, not infrequently occurred on only a portion of the root-soil interface circumference. For example, it was common for a given root to have portions of the entire root-soil interface stained and interspersed with portions that had only a relatively small segment of the root-soil interface circumference stained.

Our observations suggested, inconclusively, that there was a tendency for the partially stained portions to be spiraled around the root. This phenomenon, if found to be an actuality, will shed considerable light on root growth and root-soil void relations.

Roots cut by the top surface of the sample, but not by the bottom surface, normally had a portion of the root-soil interface, occurring near the top surface of the sample, stained for varying distances into the sample. Roots cut by either the bottom and a side or by the sides of the cylinder rarely showed signs of staining. These observations indicate that a void or space often exists between the root and the surrounding soil.

The through-flow differences found in replicated samples from a given site, brought about by the presence or absence of channels, logically raise the question as to the value of finitely bounded, relatively small diameter samples. Without question the flow through bounded samples is affected by boundary conditions. However, this through-flow difference is in itself a relevant factor that illustrates the nature and variability of macropores in forest soils.

Because of the complex interconnected network of old root channels and other macropores, many of which may rapidly conduct free water in a pipe-like manner, it is probable that the conductivity values determined on finitely bounded cores having open channels is not representative of that occurring *in situ*. In fact, such cores may actually underestimate the real conductivity rate, because only a limited number of open channels can flow in a finitely bounded sample. Those channels passing through the sample at an angle and not cut by the top and bottom surfaces

do not directly contribute to the overall flow in bounded cores, but would do so *in situ*.

The data from our 6-inch diameter samples reveal a number of trends. Only three locations will be discussed: a silty clay loam over clay (site A), a sandy loam (site B), and a silt loam (site C) that contained an exceptionally large number of old root channels. General comments apply to all locations.

The plotted curves of calculated hydraulic conductivity versus time (figs. 1 and 2), show two trends. First is the difference between depths at a given location and between locations for the same depth. Second is the marked decrease in conductivity with time. This decrease is most marked in those samples having initially high through-flow rates. The rate at which the decrease occurred was much greater for samples from the upper portion of the soil profile, which had a high overall conductivity, and

Figure 1.—Average conductivity curves for undisturbed 3-inch-thick soil samples 6 inches in diameter taken from the depths indicated at site A (a silty clay loam over clay) and site B (a sandy loam).

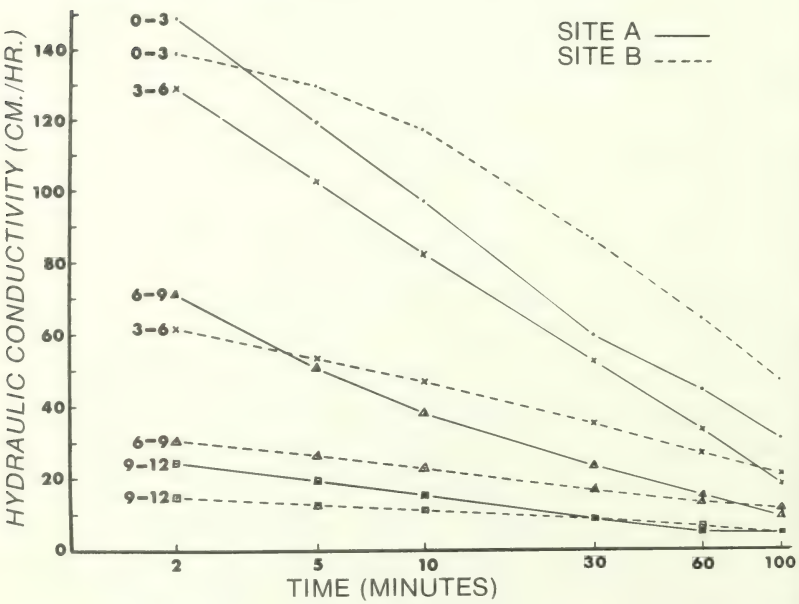
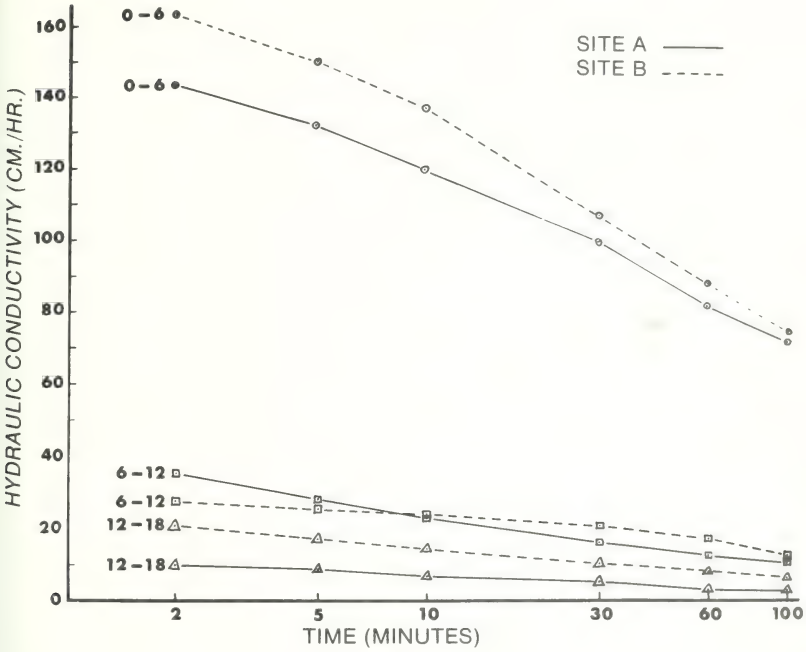


Figure 2.—Average conductivity curves for undisturbed 6-inch-thick soil samples 6 inches in diameter taken from the depths indicated at site A (a silty clay loam over clay) and site B (a sandy loam).



least for the deeper zones whose overall conductivity was relatively small.

The large decrease of conductivity with time raises several questions. What causes the rapid decrease? What time period or value should be considered as being indicative of the true conductivity? Since dissection of the samples revealed that the rapid through-flow occurred through old root channels and other macropores, can one validly calculate hydraulic conductivity values from the outflow data? It would seem logical to assume that, under the condition of rapid flow through irregular and crooked channels, turbulent flow occurred. Thus the calculated conductivity values obtained by application of Darcy's law are invalid *(Scheidegger 1957)*. However, the calculated values do have relative meaning in comparing the different sites and depths.

The cause of the rapid reduction in calculated conductivity,

which ran as high as an 85-percent reduction within 100 minutes for samples from the 3- to 6-inch depth of site A, is unknown. Numerous researchers have noted reduction in the conductivity of core samples, but usually occurring over a longer period of time. In our case, we feel that, because the samples were soaked for about 24 hours, and because of the initially rapid throughflow through old channels and the relatively short flow time (100 minutes), it seems that the probable but no doubt not the only cause of the reduction noted was particle movement. However, it must be kept in mind that dissection indicated no evidence of particle movement or relocation, although evidence of particle movement was not specifically investigated.

In general, the initial hydraulic conductivity was greater for comparable depths from the silty clay loam than for the sandy loam; and the rate of decrease as well as the total percent of decrease in conductivity was greater for the samples from the finer textured soil (figs. 1 and 2).

Since a direct relationship appeared to exist between the presence of old root channels and the calculated conductivity, a site (site C) known to have an abundance of old root channels and a texture relatively similar to that of site A was sampled and the conductivity values were obtained.

The calculated conductivity values for the 0-to-3-, 3-to-6-, and 0-to-6-inch samples were high (fig. 3). These samples had a greater overall decrease in conductivity, accompanied by a greater rate of decrease, than comparable samples from site A. However, the percentage reduction was greater for the samples taken from site A.

Dissection revealed that the samples from the upper soil levels of site C were permeated with old channels. Although samples from the deeper zones of site C had more old root channels, those channels present in the comparable samples from site A tended to be more vertical and had approximately the same frequency of intersections both at the top and bottom of the sample.

On all sites the conductivity consistently decreased, usually significantly (despite the large variation between replicated samples), with the depth of sampling. The calculated conduc-

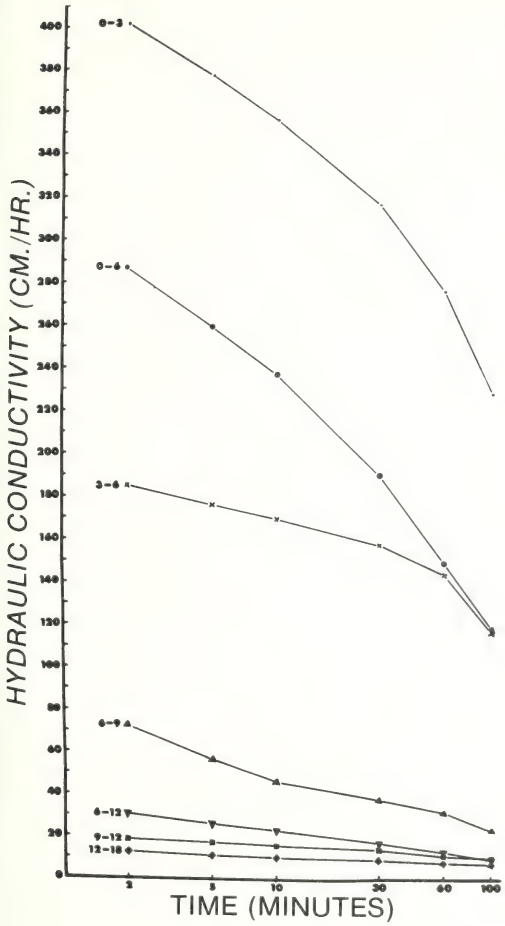


Figure 3.—Average conductivity curves for undisturbed 3- and 6-inch-thick soil samples 6 inches in diameter taken from the depths indicated at site C (a silt loam containing a large number of old root channels).

tivity at a given depth could be related directly to the soil texture and more specifically to the presence of macropores.

Qualitative and semiquantitative observations of the dissected samples revealed that the 0-to-3-inch zone was, in all cases, very porous and had a large mass of small roots. Although numerous partially decayed roots were to be found, few old open root channels were present. However, animal passageways were numerous. In general, this zone exhibited an open and highly porous network of interconnected macropores.

Between the 3- and 9-inch depths, the size and number of structural macropores decreased. In addition, evidence of animal

activity became less noticeable. The number of larger roots increased while the number of smaller roots decreased substantially.

Old open root channels, generally angling downward at about a 30° angle and frequently bark-lined, increased in size and number and became largest and most numerous within the 6- to 12-inch zone. Large structural pores were seldom observed between 9 and 18 inches, while evidence of animal activity and passageways was infrequently observed and generally was localized. The number and diameter of old open root channels decreased with depth below 12 inches.

The data indicated that the presence of open channels has an overshadowing effect on the soil matrix conductivity. For example, the sandy loam had substantially fewer root channels in the 3- to 12-inch zone than did the silty clay loam. However, the conductivity of the 3- to 12-inch zone was greater for the silty clay loam than for the sandy loam.

In addition, values for replicated samples from site A varied greatly while those from site B were much more consistent. Those individual samples from site A, not having open channels, exhibited a much lower conductivity, usually in the slow to very slow category (less than 0.125 cm./hr.), than did corresponding samples (also without open channels) from site B whose rates were generally in the moderate to moderately rapid category (2.0 to 12.5 cm./hr.).

Thus, in considering the soil's conductivity in forested soils where old open channels abound, one must direct attention to the number, size, and orientation of open channels in addition to the soil texture.

BLOCK STUDY

To obtain semi-quantitative information about the number, volume, and interconnection of old root channels, animal passageways, disturbed areas, structural cracks, and roots — and how they vary with depth and/or horizons — a large free-standing block of soil, 8 feet by 20 feet, was studied.

The data representing the soil horizons were drawn to scale (figs. 4 and 5) and were assembled into a "box" model of the

Figure 4.—A scale model representation of the soil horizons, animal passageways, "disturbed" areas, open channels, and structural cracks observed on the *front* face of the root-study block.

block. The results were revealing, especially the extent of variation in the different horizons. Although the A and B horizons varied somewhat in thickness from point to point, they paralleled the surface slope closely. However, the different C horizons were variable in thickness; and it was not uncommon for those horizons to thin out and disappear, only to reappear further along the face or on a different face.

The characterization data obtained from the free-standing block of soil, though not directly relevant to macropores, showed beyond question the variability of the soil profile. At this particular site the choice of a different location only a few feet along the block face often, sometimes drastically, changed the profile description. (See appendix for profile description of front and back faces.)

Mechanical analysis indicated that the top 9 to 10 inches, composing the A1, A2, and B1 horizons, was a silt loam for all four sides. Below 10 inches, although the actual percentages of

Figure 5.—A scale model representation of the soil horizons, animal passageways, "disturbed" areas, open channels, and structural cracks observed on the *back* face of the root-study block.

sand, silt, and clay (approximately 20, 40, and 40 percent, respectively) were similar, due to their borderline position, the textural class for a given horizon often varied all the way from a silty clay loam through a clay loam through a silty clay to a clay.

The horizons and macropore features found on the front and back faces of the block are shown in figures 4 and 5. The latter face was situated 20 feet upslope from the front of the block. The data shown in these figures are typical of those obtained from the side face and from the different dissected transects of the front and back portions of the block.

Examination of the faces represented in these figures revealed large areas that were unlike the surrounding soil matrix. These "disturbed" areas exhibited evidence of having once been old root channels or animal passageways that are now filled with a dark, highly porous, spongy material. Many of these filled root

channels could be identified as taproot or semi-taproot sites and still had portions of root bark lining the channel.

Evidence of animal activity was extensive. Numerous open animal passageways were found in the upper horizons, generally in localized areas of the soil, usually within the upper 2 feet. Passageways often seemed to be concentrated near "disturbed" areas or stones and to follow large roots.

The number, sizes, and distribution of the open root channels were surprising. The majority of these open root channels were found to have a persistent bark lining throughout the major portion of their length. This lining was frequently persistent and often remained as a hollow tube after the surrounding soil had been removed.

Relatively few open root channels were found in the upper 6 inches of the profile (fig. 5). However, this area was thickly permeated with small, apparently live, roots. Its structure was open and porous, especially in the A1 horizon. The small number of persistent root channels in this area may be a result of more rapid biological decomposition or may be due to the fact that woody roots were not originally abundant in this zone. The presence of the large number of relatively large open root channels in the 9- to 24-inch zones and the lack of large roots in that area, along with the concentration of roots — mostly relatively small — in the upper 9 inches of the profile, suggests the possibility that larger and older trees or a tree species different from that now growing on the site formed the old root channels.

Although numerous roots and some root channels were found at 6 feet, most roots and root channels were found in the upper 2 to 2½ feet. In the lower depths of the C horizon most of the roots and root channels were restricted to structural cracks while in the A and B horizons or the upper 2½ feet, the roots and root channels freely permeated the soil mass.

A very common feature, especially in the denser horizons, was the presence of live roots growing within old root channels. It was not at all uncommon to find a live root growing in an old root channel which in turn had been formed in a yet older root channel.

Tables 1 and 2 show the percentages of total surface area of each horizon that was occupied by biotic macropores. "Disturbed" areas, those portions of the profile that were dissimilar in color, texture, and structure, are included, because of their highly porous nature and the evidence that they were the remains of old roots and animal passageways. In addition, dye studies showed that these "disturbed" areas often act like open channels that conduct water rapidly.

The effect of pH and bulk density on the persistence of biotic macropores is open to question. Because of the small variation in pH values between horizons, it seems likely that the soil pH did not determine the presence or absence of biotic macropores in a given horizon. Bulk-density values consistently increased with horizon depth while the number and the area percentage occupied by biotic macropores decreased. The data seem to indicate that the size and concentration of biotic macropores may be more a function of depth than of overall bulk density. In the denser C

Table 1.—*Surface-area percentages of biotic macropores exposed in the front face, as related to horizon, depth, pH, and bulk density*

Horizon	Depth	Total biotic macro-pores	"Dis-turbed" area[1]	Open root channels	Open animal passage-ways	pH	Bulk density
	Inches	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*G/cc.*
A1	0-1	—	—	—	—	5.0	0.94
A2	1-6	36.0	28.9	2.8	4.3	4.5	1.26
B1	6-9	11.4	5.8	3.8	1.8	4.5	1.49
B21t	9-16	16.6	13.3	2.8	.5	4.6	1.61
B22t	16-23	14.4	12.6	1.8	0	4.6	1.59
IIB3	23-31	10.8	9.8	1.0	0	4.6	1.34
IIIBC	31-36	5.8	4.8	1.0	0	4.7	1.63
IIIC1	36-42	2.1	1.6	.5	0	4.6	1.72
IIIC2	42-47	2.3	2.1	.2	0	4.6	1.82
IIIC3	47-56	.8	.6	.2	0	4.6	1.78
IIIC4	56-68	1	0	.1	0	4.6	1.79
IIIC5	(60-63)	0	0	0	0	4.3	1.81
IIIC6	68-74	<.1	0	<.1	0	4.3	1.80

[1] "Disturbed" area refers to those portions of the soil profile that were dissimilar in color, texture, and structure, from the bulk of the surrounding soil mass. These areas were always darker in color and highly porous. Frequently they contained bark linings.

Table 2.—*Surface-area percentages of biotic macropores exposed in the back face as related to horizon, depth, pH, and bulk density*

Horizon	Depth	Total biotic macro-pores	"Dis-turbed" area[1]	Open root channels	Open animal passage-ways	pH	Bulk density
	Inches	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*G/cc.*
A1	0-1	—	—	—	—	5.6	0.98
A2	1-5	23.4	22.7	0.6	0.1	4.5	1.20
B1	5-9	17.0	9.9	3.4	3.7	4.5	1.45
B21t	9-16	17.4	8.9	5.5	3.0	4.5	1.62
B22t	16-24	12.0	6.2	3.5	2.3	4.7	1.70
IIBC	24-31	6.7	1.4	2.3	3.0	4.7	1.72
IIC1	31-37	2.8	1.3	1.0	.5	4.6	1.74
IIC2	37-47	1.4	0	.4	1.0	4.5	1.76
IIC3	47-51	.5	0	.5	0	4.5	1.76
IIC4	51-58	.1	0	.1	0	4.4	1.81
IIC5	58-64	0	0	0	0	4.2	1.80
IIC6	64-74	0	0	0	0	4.3	1.81
Coal bloss.	—	0	0	0	0	4.5	—

[1]"Disturbed" area refers to those portions of the soil profile that were dissimilar in color, texture, and structure, from the bulk of the surrounding soil mass. These areas were always darker in color and highly porous. Frequently they contained bark linings.

horizons, what little root growth and evidence of biotic macropores were found were restricted to structural cracks, old channels, or both.

The data in table 3 were derived from three-dimensional drawings of the features found within the 6- x 6- x 6-inch cubes from the first transect of the front face. Data from subsequent transects of the front face and the back face were similar. The calculated volumes for features within cubes varied considerably between cubes in the same layer. It was not at all uncommon for individual cubes in the B horizon to contain over 10 percent of the volume as open root channels, while the volume percentage of disturbed area often ran as high as 50 to 75 percent per cube in the A and upper B horizons.

In general, a relatively close relationship existed between the surface area percentages and volume percentages occupied by the major features. Our working experience and drawings enabled us to accurately predict the volume of roots, open channels, and

Table 3.—*Calculated root and root channel diameters, and average volume of roots, root channels, "disturbed" areas, and animal passageways found in the first dissected transect of the front face*

Depth of layers (inches)	Percent of layer occupied by —				Calculated average diameter of —	
	Roots	Channels	"Disturbed" area[1]	Animal passageways	Roots	Old root channels
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Mm.*	*Mm.*
0-6	1.1	1.5	19.4	2.1	3.9	5.8
6-12	.9	1.8	5.3	.5	4.0	6.3
12-18	.4	.4	.7	.4	2.8	3.6
18-24	.2	.2	2.0	.1	2.0	2.5
24-30	.1	.2	.4	<.1	1.8	2.6
30-36	.1	<.1	.6	<.1	1.2	1.7
36-42	<.1	<.1	1.4	<.1	.9	1.8
42-48	<.1	<.1	.6	0	.9	.5
48-54	<.1	<.1	.2	0	.7	.8
54-60	<.1	<.1	.3	0	.6	1.1

[1]"Disturbed" area refers to those portions of the soil profile that were dissimilar in color, texture, and structure from the bulk of the surrounding soil mass. These areas were always darker in color and highly porous. Frequently they contained bark linings.

disturbed areas that we could expect to find in the front half in a given cube of soil from their percentage occupation of the surface face of the cube.

We are optimistic that after we obtain more data, we shall be able to establish surface area/volume correlations whereby an estimate of the volume of macropores in a given volume of soil can be made from the percentage of the surface area occupied by these features via application of a conversion factor.

Open root channels were predominantly concentrated in the B1, B21t, and B22t horizons lying between 6 and 24 inches in depth (figs. 4 and 5; tables 1, 2, and 3). "Disturbed" areas were most bountiful in the upper 6 inches or A horizons. These areas extended some distance into the soil and many had high concentrations of additional open root channels within their boundaries. Since in many cases the upper definable portion of these "disturbed" areas appeared to occur in slight depressions, filled with highly porous material, it is reasonable to speculate that

water falling upon the surface of the forest floor rapidly enters these areas, which then act as funnels to transmit the water down into the profile and to interconnecting open or partially filled channels.

Since old root channels cannot be present in a soil profile unless roots were previously present, some brief mention of root distribution is in order. Live roots were very abundant in the A horizons and abundant in the B horizons. Although there generally were considerably more live roots than old root channels in these horizons, their larger number was compensated for by their smaller size; and consequently in the B horizons the percentages of the surface area and volume occupied by live roots were considerably smaller than those of the old root channels. Also, there were relatively few live roots that had diameters approaching those of the relatively abundant larger open root channels. No live roots were found that even began to approach the size of the "disturbed" area resulting from the filling of old root channels.

The differences noted between the number, sizes, and distribution of existing roots and old channels raises the question about the age of the persistent old root channels, their rate and time of formation, and by what age and species of tree. The present stand on the site is predominantly white oak, but evidence indicates that before World War I the area contained a heavy stocking of chestnut. The presence of roots growing in open bark-lined root channels within other similar open or partially filled channels raises the possibility that some of those persistent old channels may be of considerable age. No attempt was made in this experiment to determine the age of the root channel or the species that made it.

Macropores due to animal activity were found in the upper horizons, and they were generally associated with large roots or stones. These zoological macropores ranged all the way in size from small tunnels formed by insects up to relatively large passageways and chambers formed by mammals. Some chambers were found to contain stores of acorns.

The volume of the different cubes occupied by animal passage-

ways varied from zero up to about 80 percent. The distribution of animal passageways was highly localized: certain areas were a maze of passageways while the majority of the soil layer was devoid of passageways.

The contribution of these zoologically formed macropores to the subsurface movement of water is open to question. While many such passageways were associated with "disturbed" areas or old root channels, the majority were essentially dead-end passageways. However, many passageways did intersect open or partially filled channels at various places along their length. Probably their major contribution to flow was the association between the larger passageways and roots and stones. Dye studies showed that some flow did occur along root-soil and stone-soil interfaces that were associated with the larger passageways. How or where the flow originally entered the system was undetermined.

Summary

The experiments reported here showed that under mixed hardwood forests in northeastern Ohio, macropores in the forest floor consisted of:

- Structural pores resulting from the texture and arrangement of the primary soil particles.
- Open channels formed by the passage through the soil of woody roots that have subsequently decayed. It was observed that these old root channels frequently retained a persistent root-bark layer lining the channels.
- "Disturbed" areas, formed by root growth or animal activity, which now contain a dark, highly porous, often spongy material. These "disturbed" areas exhibited evidence of bark lining.
- Animal passageways ranging in size from small tunnels formed by insects to relatively large passageways formed by mammals.
- Voids between roots and the surrounding soil matrix.
- Structural cracks between the soil structural units.

Qualitative and semiquantitative observations of outflow from the pit faces of soil masses receiving artificial rainfall containing fluoresceine dye showed that in fine textured soils many old root channels rapidly conduct free water through the soil mass without wetting the soil mass proper. Onset of outflow after the beginning of rainfall was normally rapid, often beginning within 10 to 15 minutes. Volume of outflow per location was frequently high, exceeding 1,000 ml./min.

That free water can rapidly move substantial distances through relatively dry soil was demonstrated by an observation of seepage occurring from a pit face some 30 feet obliquely downslope from the pit under study. The seepage commenced between 30 and 45 minutes after starting to wet the forest floor above the observation pit.

Site differences were noted. Outflow from the faces of coarse textured soils was usually considerably less than that from the finer textured soils. The coarse textured soil mass tended to wet up while the fine textured soil remained essentially unwetted.

Hydraulic conductivity determinations on 6-inch-diameter cores revealed a close correlation between the presence of old root channels and overall conductivity. The data obtained indicated that the presence of an open channel had an overshadowing effect on the soil's matrix conductivity. Finitely bounded cores from soils having an abundance of open channels may lead to an underestimate of the real conductivity rate because only a limited number of open channels can flow in a finitely bounded sample, whereas *in situ* most would flow. These data emphasize that in considering conductivity of forested soils where old open channels abound, one must direct attention to the number, size, and orientation of open channels in addition to the soil texture.

Study of a large free-standing block of soil showed that biotic macropores freely permeated the A and B horizons, the greater percentage occurring in the A2 horizon. Calculated volume percentages showed that the distribution of root channels, animal passageways, and disturbed areas varied greatly throughout the profile, both horizontally and vertically. Root channels were most prevalent in the upper B horizons, where it was not uncommon

to find over 10 percent of the total volume of a 6-inch cube occupied by open root channels. The volume percentage of disturbed areas often ran as high as 50 to 75 percent of cubes from the A and upper B horizons. Macropores due to zoological activity were highly localized, certain areas being a maze of passageways while the majority of the soil layer was devoid of such passageways. In general, macropores were associated with large roots, stones, or disturbed areas.

At the experimental sites, macropores appear to persist for a considerable length of time, as illustrated by live roots growing in an old open root channel that had in turn been formed in a still older channel. However, the persistence of old root channels appears to depend somewhat on soil structure or texture. Root channels were most prevalent in the finer textured silt-silty clay loams and least in the coarser textured sandy loams. Additional evidence suggests that tree species has a definite influence on whether its roots will leave open, or partially filled root channels.

Dye studies showed that macropores provide pathways or conduits for the rapid movement of free water into and through the soil profile. Evidence of flow around live roots was also observed. Water moving within the macropores may or may not contribute to wetting up of the soil mass proper.

Qualitative observations on the benefit of macropores indicate that macropores formed in zones of high mechanical resistance and low water permeability provide avenues for the ascending and descending movement of water through the zone of resistance. The decay of the root leaves organic matter distributed throughout the root zone. In addition, old channels provide favorable growing conditions and pathways for future generations of roots.

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■

Appendix

SOIL DESCRIPTIONS

Soil type.—Clymer silt loam over clay. County: Tuscarawas. Site: TU-F1 and TU-F3.

Location.—Fairfield township SE ¼, NW ¼, Sec. 5. About 1.2 miles north of Dover Dam. U. S. Forest Service hydrology plots.

Physiography.—Dissected plateau.

Parent material.—Surficial colluvium derived primarily from Freeport sandstone, Allegheny formation.

Topography and slope.—Moderately steep south slope. Site slightly below midslope. Gradient 20 percent at site.

Drainage.—Well drained.

Use or vegetation.—White oak, beech, and hickory.

Remarks.—Site was described and sampled for mechanical analysis in conjunction with a root study on a block opened on four sides.

South or Front Face of Root Study Block 1

Depth & Horizon	
2-½ inch 01	Litter, undecomposed, from oak, beech and hickory.
½-0 inch 02	Partially decomposed organic matter.
0-1 inch A1	Very dark gray (10YR 3/1) silt loam; weak, fine granular structure; very friable; roots abundant; thickness range from ½ to 2 inches; clear wavy boundary; pH 5.0; organic carbon 12.1 percent.
1-6 inch A2	Dark brown (10YR 4/3) silt loam; weak, fine, and medium subangular blocky structure; friable; roots abundant, few abandoned root channels; common fine pores; lower boundary gradual and smooth; pH 4.5; organic carbon 1.2 percent.
6-9 inch BI	Yellowish brown (10YR 5/4) heavy silt loam; weak, fine, and medium subangular blocky structure; slightly sticky when wet; numerous roots, pipings, or abandoned root channels are common ranging from 3 to 20 mm. in diameter; less than 5 percent coarse skeletal material; lower boundary gradual and smooth; pH 4.5; organic carbon 0.5 percent.
9-16 inch B21t	Yellowish brown (10YR 5/6) silty clay loam; moderate, medium subangular blocky structure; firm, sticky, and plastic when wet; roots common; thin, patchy clay films on ped surfaces; common fine pores; 3 to 5 percent coarse skeleton of sandstone fragments; lower boundary gradual; pH 4.6; organic carbon 0.4 percent.
16-23 inch B22t	Yellowish brown (10 YR 5/8) silty clay loam with common olive (5Y 5/3) and reddish brown (5 YR 5/4) variegations; moderate, medium subangular blocky structure; firm, sticky, and plastic; thin clay films on channel walls, and

patchy on ped surfaces; roots common, but decreasing in number; 10 percent coarse skeleton of sandstone and shale fragments; lower boundary abrupt and irregular; ph 4.6; organic carbon 0.3 percent.

23-31 inch IIB3 — Yellowish brown (10YR 5/4) loamy coarse sand with thin bands of gray (10 YR 6/1) sandy loam; weak, coarse subangular blocky structure that crushes to single grain; very friable; few roots observed, coarse skeleton material 40 percent; horizon is discontinuous; abrupt irregular lower boundary; pH 4.6; organic carbon 0.3 percent.

31-36 inch IIIBC — Gray (5Y 6/1) silty clay loam with many (25 percent) strong brown (7.5YR 5/6) mottles; moderate, coarse, subangular blocky structure; very firm; few small roots, weathered clay shale fragments common; ped faces have moderately thick clay films; lower boundary clear; pH 4.7; organic carbon 0.3 percent.

36-42 inch IIIC1 — Dark gray (N4/) silty clay with strong brown (7.5YR 5/6) and gray (10YR 6/1) mottles; platy to massive; very firm; few small roots growing in structural cracks; lower boundary abrupt; pH 4.6; organic carbon 0.3 percent.

42-47 inch IIIC2 — Brown (10YR 5/3) silty clay loam with strong brown (7.5YR 5/6) and gray (10YR 6/1) mottles; weak, coarse, subangular blocky structure to massive; firm, occasional small roots, thin lenses of coal blossoms; lower boundary clear, wavy; pH 4.6; organic carbon 0.8 percent.

47-56 inch IIIC3 — Mottled grayish brown (10YR 5/3) and dark gray (N4/) silty clay loam; massive, firm, sticky, and plastic; thin coal blossom bands; lower boundary clear; pH 4.6; organic carbon 0.3 percent.

56-68 inch IIIC4 — Mottled olive brown (2.5Y 4/4), light olive gray (5Y 6/2) and grayish brown (2.5Y 5/2) silty clay; massive; firm, sticky, and plastic; lower boundary clear; pH 4.6; organic carbon 0.6 percent.

68-74 inch IIIC6 — Light olive brown (2.5Y 5/6) silty clay with many (30 percent) gray (10YR 6/1) mottles; massive; sticky when wet; pH 4.3; organic carbon 0.1 percent.

North or Back Face of Root Study Block 1

Depth & Horizon

1-½ inch 01 — Undecomposed litter from oak, hickory, and beech.

½-0 inch 02 — Partially decomposed organic material.

0-1 inch A1 — Very dark gray (10YR 3/1) silt loam; weak, fine granular structure; friable; roots abundant; thickness range from ½ to 2 inches; clear wavy boundary; pH 5.6; organic carbon 13.4 percent.

1-5 inch A2 — Brown (10YR 4/3) silt loam; weak, fine subangular blocky structure; friable; roots abundant; lower boundary gradual smooth; pH 4.5; organic carbon 1.9 percent.

5-9 inch B1	Yellowish brown (10YR 5/4) silt loam; weak, fine to medium subangular blocky structure; firm; numerous roots; lower boundary gradual smooth; pH 4.5; organic carbon 0.8 percent.
9-16 inch B21t	Yellowish brown (10YR 5/6-5/8) clay loam; moderate, medium subangular blocky structure; firm, sticky when wet; few roots; occasional large sandstone cobbles observed; thin patchy clay films on ped surfaces; lower boundary clear smooth; pH 4.5.
16-24 inch B22t	Yellowish brown (10YR 5/6) heavy silty clay loam with few strong brown (7.5YR 5/6) pale brown (10YR 6/3) mottles; moderate, medium subangular blocky structure; firm, sticky when wet; few roots; thin patchy clay films on ped surfaces and channel walls; less than 5 percent coarse skeleton; lower boundary clear smooth; pH 4.7.
24-31 inch IIBC	Light olive gray (5Y 6/2) silty clay with few, distinct, strong brown (7.5YR 5/6) and yellowish red (5YR 4/6) mottles; weak, medium and coarse subangular blocky structure; firm, sticky and plastic; numerous abandoned root channels observed; discontinuous lenses of sandy material and sandstone fragments occur in this horizon; clay films on ped surfaces; lower boundary clear; pH 4.7.
31-37 inch IIC1	Light olive brown (2.5Y 5/4) silty clay with dark yellowish brown (10YR 4/4) coatings; massive to prismatic; firm, sticky and plastic; numerous soft brittle shale fragments (10 percent); lower boundary gradual wavy; pH 4.6.
37-47 inch IIC2	Grayish brown (2.5Y 5/2) (60 percent) and yellowish brown (10YR 5/6) silty clay; massive; firm, sticky and plastic; lower boundary abrupt smooth; pH 4.5.
47-51 inch IIC3	Yellowish brown (10YR 5/6) silty clay loam with grayish brown (2.5Y 5/2) mottles; relict platy to massive; firm, sticky; bands of very dark gray (N3/); coal blossom; pH 4.5.
51-58 inch IIC4	Light olive brown (2.5Y 5/4) clay with yellowish brown (10YR 5/6) mottles and bands of dark gray (N4/) coal blossom; relict platy structure; firm, sticky and plastic; lower boundary abrupt smooth; pH 4.4.
58-64 inch IIC5	Gray (5Y 6/1) clay with gray (10YR 5/1) coatings and yellowish brown (10YR 5/6) mottles; massive to prismatic structure; very firm, sticky and plastic; lower boundary abrupt; pH 4.2.
64-74 inch IIC6	Light olive gray (5Y 6/2) silty clay loam with yellowish brown (10YR 5/6) streaks; massive to prismatic structure; firm; pH 4.3.

THE FOREST SERVICE of the U. S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

by Everette D. Rast

Preliminary Work in Developing SAWBOLT GRADING *Systems for White Oak*

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Preliminary Work in Developing SAWBOLT GRADING Systems for White Oak

TOWARD TOTAL TREE UTILIZATION

ONE WAY to cope with the increased demand for wood is to strive toward total tree utilization during timber harvesting. Greater use of bolts (sections of the tree stem shorter than 8 feet) will play an important role in attaining this goal. By using bolts, loggers can utilize tree sections considered unmerchantable under present utilization practices.

According to Gill and Phelps *(4)*, use of boltwood by manufacturing industries increased 61 percent from 1960 to 1965. Manufacturers of wood products have realized that the cutting patterns their production lines demand can often be satisfied better economically by the short lumber from bolts than by crosscutting and ripping longer lumber. As the use of bolts increases, the need for and the benefits from a bolt-grading system will become apparent to the logging and milling industry.

This paper is principally a description of one technique used in the development of white oak *(Quercus alba L.)* sawbolt grades—not a final sawbolt grading system for the species over its range. This technique can be used by anyone in developing other bolt-grade specifications or in refining the system presented in this paper.

SAMPLE DATA

The sample of 164 bolts used in this study came from 61 white oak trees cut in southern Illinois. Only trees that would produce straight and sound bolts were bucked, using all the stem to a 6-inch top diameter. No bolts were cut from limbs. Bolts damaged in logging were excluded. The diameter of the sample bolts ranged from 6 to 14 inches; and lengths were 4, 5, and 6 feet (table 1). All bolts were diagramed, the number of clear faces was tallied, and the bolts were sawed through and through on a portable bolter saw. See Appendix for sawing techniques. Each board was diagramed, using a system of rectangular coordinates to delineate the board outline and all defects within the board.

ANALYSIS OF DATA

Method of Analysis

Multiple regression techniques were used to evaluate the relationship of volume in Clear One Face and Better lumber (C1F & B) in a bolt to ten independent variables. C1F & B = the surface area of all C1F or C2F cuttings from all of the boards in each bolt, expressed as board feet measure.

To test the proposed grading systems, analysis of variance by use of the pooled residual mean square was used. From information derived from work with developing log and tree grades, and the knowledge that, in bolts, length and diameter are the key to the prediction of volume, the following hypothesis model was formed:

$$Y_{(C1F\ \&\ B)} = a + b_1 X_1 + b_2 X_2 + e$$

in which:

$Y_{(C1F\ \&\ B)}$ = Board-foot volume of Clear One Face & Better Lumber.
X_1 = Length.
X_2 = Diameter squared.
e = Error.

The hypothesis model was tested against each maximum model (the proposed trial models thought to be an improvement over the hypothesis model) *(3)*.

Table 1.—*Distribution of 164 white oak bolts by diameter class, bolt length, and number of clear faces*

Diameter class (inches)	Bolt length and number of clear faces															Total
	4 feet					5 feet					6 feet					
	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	
6	1	—	—	—	—	2	—	—	—	—	2	—	—	—	—	5
7	2	—	—	1	—	6	2	—	—	—	—	1	—	—	—	12
8	6	1	1	—	3	8	1	2	1	1	3	1	—	—	—	28
9	4	1	1	1	—	3	2	1	2	2	3	—	2	—	2	24
10	5	4	1	4	2	5	1	2	3	—	5	2	—	3	—	37
11	2	1	1	3	—	4	4	1	1	1	2	2	1	1	1	25
12	—	2	—	3	3	—	—	2	2	1	—	2	—	1	2	18
13	—	—	1	2	3	—	—	1	—	—	—	—	2	—	3	12
14	—	—	—	1	—	—	—	—	1	—	—	—	—	1	—	3
Total	20	9	5	15	11	28	10	9	10	5	15	8	5	6	8	164

Variables

The dependent variable, volume of Clear One Face and Better lumber (C1F & B) in a bolt, was expressed in terms of board-foot volume of 4/4 air-dried lumber. The total board-foot volume and the volume of C1F & B for each bolt was determined by use of a computer program developed at the Forest Products Laboratory *(5)*. Dunmire and Englerth have explained the method of obtaining the data for this yield program *(2)*. To conform to the program's limitation of 100 cutting sizes, 10 widths and 10 lengths were used. These cutting sizes range in width from 1½ to 6 inches in ½-inch increments, and in length from 12 to 48 inches in 4-inch increments. The selection of widths and lengths used was made after considering the quality and dimensions of the boards in the study.

The following 10 variables were considered independent in developing trial bolt-grading systems:

X_1 = Length (L), rounded to the last whole foot.
X_2 = Diameter (Dia.) rounded to the nearest inch (e.g., 7″ = 6.6″ to 7.5″) and measured inside the bark at the small end of the bolt.
X_3 = X_2 squared (Dia.^{2}).
X_4 = X_1 times X_3 (L x Dia.^{2}).
X_5 = Dummy variable *(1)* one (D-1) 4 clear faces.
X_6 = Dummy variable two (D-2) 3 clear faces.
X_7 = Dummy variable three (D-3) 2 clear faces.
X_8 = Dummy variable four (D-4) 1 clear face.
X_9 = Dummy variable A (NED) — no end defect.
X_{10} — Dummy variable B (ED) — has end defect.

Clear face is defined as one-fourth the circumference of a bolt for its entire length, and containing no defects. Light bark distortions and low bumps were not considered defects.

Clear faces (No.)	Dummy variables D_1	D_2	D_3	D_4
4	+1	0	0	0
3	0	+1	0	0
2	0	0	+1	0
1	0	0	0	+1
0	−1	−1	−1	−1

End defects: +1 has end defect.
−1 no end defect.

Formulation of Preliminary Models

Regression analyses were run on number of clear faces and sound end defects, and the F-statistics were developed to test their significance. The number of clear faces proved to be highly significant, but the presence or absence of end defects did not, principally because only sound end defects were allowed, and the number of these were minimal. All the variables were run on a step-wise regression program, and only length times diameter squared·and number of clear faces proved to be significant at the 5-percent level.

Preliminary plots of percent of C1F & B over diameter, volume of C1F & B over number of clear faces, and percent of C1F & B over number of clear faces, indicated that a three-grade system would fit this data better than a two-grade system.

Model Selection

Two trial grading systems were developed; one was based on number of clear faces, and the other was based on percent of clear cuttings on the three best faces. Only two- and three-grade models were tested. Eight modifications of the two systems were made. The test statistics used in comparing the models are given in table 2.

In setting up the modifications, first, only the number of clear faces was considered; then diameter and length restrictions were added. Next a system based on the percent of clear cuttings on three best faces was set up (this system was patterned after a bolt-grading system devised by Carpenter and Lockard). Finally, a combined system was set up, using both types of models. The 50 percent clear on the three best faces ties in with the percent-

Table 2.—*Specifications, pooled mean squares, and the overall F for the test of significance for each trial grading-system model*

Grading system model	Grade	Grade specifications	Pooled residual mean square for model	Overall F statistic for model
A	1	1-4 CF[1]		
	2	0 CF	4.2106	60.95**
B	1	1-4 CF: 9 - 14″		
	2	1-4 CF: 6 - 8″ 0 CF: 6 - 14″	4.2840	58.55**
C	1	3-4 CF		
	2	1-2 CF	3.6825	41.05**
	3	0 CF		
D	1	4 CF		
	2	1-3 CF	3.2928	50.55**
	3	0 CF		
E	1	4 CF: 9 - 14″; 5 - 6′ 4 CF: 12 - 14″; 4′		
	2	4 CF: 6 - 8″; 5 - 6′ 4 CF: 6 - 11″; 4′ 1-3 CF	3.2850	50.75**
	3	0 CF		
F	1	Butts: 6 - 14″; 100% clear on 3 best faces Uppers: 10 - 14″; 100% clear on 3 best faces		
	2	Butts & Uppers: 8 - 14″, ⅔ clear on 3 best faces	3.5973	42.95**
	3	Butts & Uppers: 6 - 14″, No restrictions on faces		
G	1	4 CF: 9 - 14″; 5 - 6′ 4 CF: 12 - 14″; 4′		
	2	50% clear on 3 best faces, 4 - 6′	3.1425	54.85**
	3	6 - 14″; 4 - 6′		
H	1	4 CF: 10 - 14″; 5 - 6′ 4 CF: 12 - 14″; 4′		
	2	50% clear on 3 best faces, 8 - 14″; 4 - 6′	3.2558	51.58**
	3	6 - 14″; 4 - 6′		

[1]CF = clear face.
** = Significant at the 1-percent probability level.

yield figures, and no restrictions were placed on the grade-3 bolts except for the minimum size bolt accepted, because all bolts had to be sound and free of crook and sweep.

The associated tests statistics confirmed the choice of the three-grade model over the two-grade model for these data (table 2).

The following *a priori* restrictions were applied to each three-grade system that was developed:

Grade	C1F & B
B-1 =	Over 65 percent
B-2 =	46 to 65 percent
B-3 =	25 to 45 percent

Although model H, the selected trial grading system, did not have the lowest pooled residual mean square, it was chosen because it was the only model that satisfied the *a priori* restrictions (table 3). Two cells (8 inch and 4 foot in grade 2 and 6 inch and

Table 3.—*Volume of C1F & B and percent of total volume for the selected grading system*

Diameter (inches)	4 feet		5 feet		6 feet	
	Volume in C1F	Percent of total volume	Volume in C1F	Percent of total volume	Volume in C1F	Percent of total volume
	Bd. ft.	*Pct.*	*Bd. ft.*	*Pct.*	*Bd. ft.*	*Pct.*
			GRADE 1			
10	—	—	14	78	16	73
11	—	—	17	77	20	74
12	16	76	20	74	24	73
13	19	76	23	72	28	74
			GRADE 2			
8	4	44	6	55	7	50
9	6	55	8	57	10	56
10	8	57	10	56	13	59
11	10	56	13	59	16	59
12	12	57	16	59	20	61
13	15	60	20	63	24	63
14	18	62	23	62	28	62
			GRADE 3			
6	2	50	2	33	3	43
7	2	33	3	37	4	40
8	3	33	4	36	5	36
9	4	36	6	43	7	39
10	6	43	7	39	9	41
11	7	39	9	41	11	41

Table 4.—*Specifications for the selected trial grading system*

Grading factors	Grade						
	B-1		B-2			B-3	
Length (w/o trim)	5′ - 6′	4′	4′ - 6′			4′ - 6′	
Diameter (min. top)	10″	12″	8″			6″	
				% in clear cuttings:	50		
Faces	No defects* allowed on any face		Best 3 faces	Max. No. of cuttings:	2	No restrictions	
				Min. length of cuttings:	2′		
Sweep**	—			—		—	
Interior scalable defects**	—			—		—	
End defects**	—			—		—	

*Low bumps and light bark distortions were not considered grading defects in this study.
**All study bolts were straight and sound, and end defects were minimal.

4 foot in grade 3) failed to meet the restrictions, but it was felt that, with more data, these percentages would come within the standards set. The specifications for the selected grading system are given in table 4.

The following are the prediction equations for the three grades of the selected grading system:

$$\text{B-1 } Y_{C1F\ \&\ B} = -0.4650 + 0.0281\,X_1$$
$$\text{B-2 } Y_{C1F\ \&\ B} = -3.0545 + 0.0268\,X_1$$
$$\text{B-3 } Y_{C1F\ \&\ B} = -0.6990 + 0.0156\,X_1$$

where:

$X_1 =$ Length x Diameter^2

See table 5, Appendix, for relevant statistics associated with each equation and table 6 for individual bolt reliability.

No extrapolation was attempted, which is why grade B-1 stops at 13 inches and grade B-3 stops at 11 inches.

A volume table, to the nearest board foot, was developed from all 164 bolts and fitted by the least-squares technique (table 7, Appendix).

SUMMARY AND CONCLUSIONS

The principal objective of this study was to develop a technique that may be used in future studies of bolt grades. A grading system was developed for white oak saw bolts, with the restrictions imposed by the available data.

A grading system for sawbolts must not be too time-consuming in application, for as the grading time increases, the benefit obtained approaches the cost of grading. If the developed grades are used, the following points should be kept in mind:

- Only straight and sound bolts were used.
- The sawing was done by slabbing a non-clear face and then sawing a clear face until conversion was complete.
- In selecting the bolts, no segregating was done as to product class, therefore yields may be overestimated or underestimated for a given product class.
- The yields are based on 1-inch material remanufactured into cuttings 1½ inches by 12 inches and larger.

■

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■

APPENDIX

Standardized Sawing Method For Each Combination of Clear Faces

1. *Class 1 bolts (four clear faces).* One face was slabbed. One or more boards were sawed from this face to provide a good bearing surface. (This was done for all classes of bolts.) The bolt was then turned down 90 degrees and sawed through and through until conversion was completed.

2. *Class 2 bolts (three clear faces).* The unclear face was slabbed and the bolt turned own 90 degrees and sawed through and through until conversion was completed.

3. *Class 3 bolts (two opposite clear faces).* The bolt was placed on the carriage with one of the clear faces up, and the adjacent face was slabbed. The bolt was then turned down 90 degrees and sawed through and through until conversion was completed

4. *Class 3 bolts (two adjacent clear faces).* The bolt was placed on the carriage with one clear face up, and the adjacent clear face was slabbed. The bolt was then turned 90 degrees and the remaining clear face sawed through and through until conversion was completed.

5. *Class 4 bolts (one clear face).* The bolt was placed on the carriage with the clear face up, and the adjacent face was slabbed. The bolt was then turned 90 degrees and sawed through and through until conversion was completed.

6. *Class 5 bolts (no clear faces).* The bolt was placed on the carriage with the major defects cornered, and the first face was slabbed. The bolt was then turned 90 degrees and sawed through and through until conversion was completed.

Table 5.—*Relevant statistics for the three sawbolt prediction equations*

Independent variable	Regression coefficient	Standard deviation
	GRADE B-1	
Intercept	—0.4650	2.7292
L x Dia.^{2}	0.0281**	0.0036
$R^2 = 0.81$		
Standard error of residual = 2.33		
No. of observations = 16		
	GRADE B-2	
Intercept	—3.0545**	0.6348
L x Dia.^{2}	0.0268**	0.0011
$R^2 = 0.87$		
Standard error of residual = 2.00		
No. of observations = 88		
	GRADE B-3	
Intercept	—0.6990	0.5009
L x Dia.^{2}	0.0156**	0.0013
$R^2 = 0.72$		
Standard error of residual = 1.39		
No. of observations = 60		

**Significant at 1-percent level.

ble 6.—*Distribution of bolts with regard to meeting of C1F & B specifications*[1]

Diameter class (inches)	Grade	Less than required % C1F & B	More than required % C1F & B	Within specifications	Total
		No.	*No.*	*No.*	*No.*
6	B-3	1	—	4	5
7	B-3	4	2	6	12
8	B-2	6	1	6	13
	B-3	1	4	10	15
9	B-2	1	4	9	14
	B-3	—	5	5	10
10	B-1	—	—	1	1
	B-2	—	3	21	24
	B-3	—	2	10	12
11	B-1	1	—	1	2
	B-2	—	1	16	17
	B-3	—	4	2	6
12	B-1	4	—	3	7
	B-2	—	1	10	11
13	B-1	1	—	5	6
	B-2	—	3	3	6
14	B-2	—	2	1	3
	Total	19	32	113	164

ecifications:
Grade B-1 = Over 65% C1F & B
Grade B-2 = 46 to 65% C1F & B
Grade B-3 = 25 to 45% C1F & B

Table 7.—*Volume table (fitted by least-squares technique)*

Diameter (inches)	Length, feet		
	4	5	6
	Board feet		
6	4	6	7
7	6	8	10
8	9	11	14
9	11	14	18
10	14	18	22
11	18	22	27
12	21	27	33
13	25	32	38
14	29	37	45

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TOWARD INTEGRATED CONTROL

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INTRODUCTION

by ROBERT W. CAMPBELL, USDA Forest Service, Northeastern Forest Experiment Station, Hamden, Connecticut.

ANY PROGRAM of integrated control is likely to be much more expensive than complete reliance on pesticides *in the short run*, especially if we restrict our thinking to the cost of program development. Clearly, the use of pesticides was more appealing in the years before publication of *The Silent Spring*. Not only did our operational systems consist primarily of one-dimensional pesticidal applications, but little research effort was devoted to the development of supplemental or alternative methods. DDT seemed to be a miracle remedy; that was all one had to know or care about!

Now a rising tide of public concern over possible adverse side effects of pesticides has resulted in increasing constraints on their use. And perhaps largely as a consequence of these constraints we are now beginning to see increasing adverse effects from the pests themselves. In the face of this, it seems both remarkable and tragic that we have yet to really face up to the increasingly urgent need to produce supplemental or alternative population-management systems.

Where do we go from here? First, we have to recognize that broad, flexible, and ecologically sound programs will not only cost a lot of money to develop but also that this development will take time. We then have to get this message across to a public that invariably wants action programs now! Second, we will have to plan ahead as carefully as possible. Scattered and uncoordinated research and control work usually result in findings that cannot be combined efficiently *a posteriori* to contribute to problem solution. Our efforts will have to be coordinated more closely in the future than they have been in the past.

TOWARD INTEGRATED CONTROL

by D. L. COLLINS

I HAVE a suspicion that the word "integrated" is one of the most overworked and misused terms in common circulation today, including its use when coupled with the word "control" with reference to insect pests. Therefore, before devoting an entire conference to the subject of "integrated control", we might do well to see if we know what it really means.

The word "integrated" is derived from the Latin adjective "integer", which originally meant "untouched" or "entire". When converted into a verb and then, with the past tense used as an adjective again—that is, the word "integrated"—its meaning according to Webster is: "composed of separate parts united together to form a more complete, harmonious, or coordinated entity".

For the word control we find several meanings, ranging from "power or authority to guide or manage" to "reduction or regulation of the wildlife population of an area by killing". Presumably the latter meaning conforms most closely to the interpretation commonly understood in the expression "integrated control".

If we substitute these definitions for the words we are defining, we come up with "reduction or regulation of the wildlife population of an area by killing (by use of) several separate parts united together to form a more complete, harmonious, or coordinated entity". Or, if we start fresh with the meaning of the word "integer", we would guess that integrated control would mean "complete control"—although this is not the way we usually understand it.

Thus we see that the common entomological meaning and the actual etymological meaning of the term are somewhat at variance. In spite of this semantic confusion, or perhaps even because of it, the expression "integrated control" has certainly caught on with the public as well as with entomologists. However, its ambiguity allows it to mean different things to different people, and therein lies a difficulty and danger. To a person confronted with an urgent pest problem, it is rather risky to recommend "integrated control", especially if you have to stay around and explain what you mean by it in terms of positive action to solve a particular problem. Yet, if we are to continue to use the expression, we must be prepared to accompany it with pertinent, useful advice. Otherwise the term becomes a fatuous subterfuge for avoiding the issue.

Possibilities

Historically, in forest entomology, or rather, in the control of forest insect pests, before the recent era of reliance on pesticides, the approach was basically one which we would now call "integrated". Such well-known and widely respected forest entomologists as S. A. Graham were emphasizing the suppression or regulation of forest pests by attention to certain biological facts and various cultural practices long before the term "integrated" began to be thrown around so loosely. Graham always emphasized means of control other than chemical, and I think we might well return to his early principles and precepts in an attempt to appraise the present situation.

Until recently it was thought by many persons, or at least hoped, that a control of the gypsy moth, or a way to stop its spread, could be developed in time to keep it from overrunning the southern and western Appalachian forests. Hence a belated, but intensive, almost desperate, effort to learn more about it, and to try anything that seemed to offer a chance of halting its advance. At about the same time that the program of total suppression and prevention of spread began to appear hopeless, the situation was further aggra-

vated by the furore about insecticides. Research on other possible control methods, which had already been under way, suddenly acquired stronger support, and many new possibilities received attention. A serendipitous result of the intensive work on gypsy moth has been the development of information that can also be applied to other forest pests as well.

A review of possible control methods for this insect would certainly include the following:

Release of sterile males.

Sex attractant pheromones.

Genetic manipulation.

Parasites.

Invertebrate predators.

Vertebrate predators.

Pathogens.

Feeding inhibitors.

Environmental manipulation.

Chemical pesticides.

Each of these methods has found a place somewhere in the control program for one or more pests. We all know, for example, of the use of the sterile males released against the screwworm, the use of lady beetles against scale insects in California, the use of *Bacillus thuringiensis* against cabbage loopers, and so on.

Unfortunately, each individual instance of success depends on a special set of circumstances that may be difficult or impossible to duplicate or approximate with some other species. This fact is often very difficult to get across to the public, who see this or that "new" technique as a breakthrough on old fronts. The sterile male technique, for example—or the use of specific pathogens and parasites—to be really workable may require that there be a practical way either to rear or to trap the insects in large numbers and to maintain continuous rearing or access to large natural populations. These procedures must be worked out separately for each species. They may include

the development of artificial foods and extensive and expensive greenhouse and insectary facilities manned by many persons with special training and duties.

Watchful Waiting

The economic factor is an important one, and one that in forest entomology problems is especially difficult to assess. The question "Is it worth the expense?" usually comes up eventually; and then we get into the realm of opinions and emotions and long-range effect, which makes it virtually impossible to give satisfactory answers—at least not without extensive applied research. Even with proven, if limited, success for a given control in a specific instance such as sterile males against screwworm or fruit fly, or virus against sawflies, or milky disease against Japanese beetle, we are on the defensive with every would-be control agency, whether it is a commercial applicator, a property owner, a garden club, or a public agency, unless, after we have said he can't or shouldn't spray, we can tell him something else to do that is really practical: where to get it, how to use it, or who can do it, and what to expect from it. Until we can do this, we are not very far along toward integrated control.

If we are honest, we have to admit that, with one or two exceptions, control of forest pests on a short-notice basis as a program with specific recommended steps is not now predictable with anything except sprays. Even with the exceptions, most of the measures that can be used require such exacting attention to technique and methods that they simply will not work except in the hands of specially trained personnel, and even then only under special conditions.

I think we are facing a long period of watchful waiting, in which, however, we must always be on the alert for a breakthrough. During this period, research will be continued and intensified. An occasional success will be hoped for, and will probably occur, and will certainly be needed to keep up enthusiasm, optimism, and support.

During this period we may learn that we do not need all the

control we thought we did. And since it is fairly certain we won't get it, the only thing we can do is to learn to live without it, and in the meantime to understand and encourage the natural control factors we have listed and any others that may be present, in any given situation. We may discover that what we really mean by "integrated control" is only the weighting of the balance of nature in what we consider to be a favorable direction. Our research programs are to help us increase these weights and show us how to apply them.

■

POPULATION QUALITY

by DAVID E. LEONARD
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I AM CERTAIN that I do not have to convince anyone here that the quality of individual organisms can vary, and that individual differences can have a marked effect on the population biology of a species. In 1957, Wellington stated:

> "Populations are composed of individuals, and individuals differ. Nevertheless, our attempts to identify and evaluate the factors regulating animal numbers frequently seem to include a tacit assumption that the populations thus regulated are monolithic, or else consist of well-nigh interchangeable units that respond uniformly to given biotic or physical factors. Thus, students of population dynamics seldom determine the proportions of physiologically or genetically different groups within a generation or allow for the possibility that these proportions might change between generations as the population density changes."

This was the opening statement in Wellington's paper on individual differences as a factor in the population dynamics of the western tent caterpillar, *Malacosoma pluviale*. Although Franz (*1950*) and Chitty (*1957*) had hypothesized that differences in populations, particularly genetic differences, could affect the fate of populations, Wellington's studies were one of the first definitive works, showing that qualitative changes could influence the population dynamics of insects.

The effects of variations in population quality are probably best documented in the literature on small mammals, particularly microtine rodents. During the cycles of abundance of voles

and lemmings, many changes in population quality have been shown to affect the endocrine system, behavior, and reproduction. The mechanisms inducing these qualitative changes are either intrinsic, such as the effects of crowding, or changes in behavior; or they are extrinsic, such as differences in the quality or quantity of food.

Qualitative differences are known in insects. Phase polymorphism, density-related responses, many behavioral changes, and wing polymorphism can be a result of, or result in, differences in the quality of individuals. Differences in viability, fecundity, longevity, vigor, fitness—all of these can result from qualitative change.

I hope to demonstrate that:

- Population quality can be important in the dynamics of insect populations.

- Qualitative changes need not be based on genetically induced changes, as suggested by Chitty (*1960*), but may operate through induced physiological changes.

- Factors inducing qualitative changes can be considered in the formulation of techniques of pest management.

To show that individual differences in quality should be considered in understanding the population dynamics of a species, I will review briefly some of the work of Wellington on the western tent caterpillar, then will discuss my investigations of the gypsy moth, *Porthetria dispar* (L).

In 1957, Wellington showed that newly hatched caterpillars of the western tent caterpillar differed in their response to light. He was able to separate larvae into various categories according to their response. One component, called type I larvae, were the most responsive to light, ate more, and developed rapidly. A second component, called active type II larvae, were less responsive to light and developed slightly less rapidly than the most active component. The third component, called sluggish type II larvae, developed slowly and often fed less because they spent more time in the tent. In rearings, when type I or type and active type II larvae were combined, the colony was vigor

ous; but when pure type II larvae were reared, survival was poor. Adults showed the same pattern of activity as the larvae from which they came. More active larvae produced more active adults, which were more vigorous fliers and dispersed to establish new and distant infestations. Thus new infestations consist initially of active colonies, and these active colonies are characterized by the elongate shape of their tents.

Gypsy Moth Work

When I started to work with the gypsy moth, I decided to concentrate my efforts on determining whether a similar intrinsic mechanism might be operating and masking the attempts to explain, on the basis of abiotic factors, the causes of the population fluctuations common to this defoliating lymantriid. These population flushes can be very dramatic. They occur mostly on the higher elevations containing favorable host trees, primarily species of oaks.

In the Northeast, the gypsy moth problem involves more than damage to a cash timber crop. In recreation areas, gypsy moth outbreaks seriously curtail their use. Furthermore, many people who live in the suburbs, which are frequently wooded, object to sharing their ecosystem with other organisms, particularly insects. Pressure (often political) is applied to "solve the gypsy moth problem". The continued quest for immediate solutions does not provide a suitable situation for sustaining the biological and ecological investigations necessary to prevent or even predict outbreaks. As a result, after 100 years, and expenditures of tens of millions of dollars, we know little more about the gypsy moth than the information published by Forbush and Fernald before the turn of this century.

It is difficult to work in the laboratory with insects that require fresh foliage, and a wheat germ diet was modified for gypsy moth larvae (*Leonard and Doane 1966*). I wanted next to determine the rate of development of larvae on the diet, at the temperature and light regimes to be used in subsequent studies—16 hrs. photoperiod per 24-hr. day, and 23.5°C. About 60 larvae were isolated at hatch and reared individually in petri

dishes. They were checked each day; the frass was removed for drying and weighing; and the day of each molt was recorded. When the larvae were in what I thought should be the last larval stage—the 5th instar in males and the 6th in females—it was apparent that some larvae were going to molt again: to a 6th instar in males and a 7th in females. Of the 58 larvae reared, 26 had an additional stadium (*Leonard 1966*).

A check of the literature showed that the occurrence of an additional instar was known for this species, at least since the studies of Fernald (*1896*).

I probably would have not considered the occurrence of an additional molt further had I not data to compare those larvae with "normal" larvae. These differences in gypsy moth larvae that have undergone an additional instar (*Leonard 1966*) are outlined below:

1. Prolonged instar I, with longer prefeeding phase.
2. Prolonged development to adulthood.
3. Increase in pupal weight (fecundity).
4. Shortened pupal stage.

Additional Molt

I didn't realize it at the time, but with these data I had uncovered the response to a qualitative change that functions as a self-regulating mechanism as the gypsy moth population density increases. If you will accept for a few moments that the occurrence of an additional molt is evidence of a response to a qualitative change, I would like to discuss how this response can be triggered, before discussing the importance of the qualitative change in the population biology of the gypsy moth.

Additional larval stadia can be induced during early larval development: (1) crowding (*Leonard 1968*), (2) starvation (*Leonard 1970a*), and (3) cool temperatures (*Leonard 1968*).

The crowding experiments were conducted not to determine the effect on the number of molts, but rather to check the effects of crowding on the rate of development. In field populations, adults are often found 1 to 2 weeks earlier in dense populations than they are in sparse ones. To determine the effects

of crowding on the rate of development, about 800 larvae were crowded; and these were compared with about 200 larvae that were reared in isolation (*Leonard 1968*). The rates of development were recorded in such a manner that it was possible to reconstruct the molting records for each larva in the crowded cultures. When these data were compared with those from larvae reared in isolation, these effects of crowding gypsy moth larvae (*Leonard 1968*) appeared:

1. Prolongation of instar I, followed by a more rapid rate of development in subsequent instars.
2. Lower pupal weight.
3. Increase in the number of larvae with an additional instar.
4. Lighter coloration of adult males.

The rate of development to adulthood in crowded cultures was faster than in isolated ones, but the increased rate was not a generalized increase in all instars. In instar I, the rate of development was slower, whereas in instars II, III, and IV the rate of development was faster. In both sexes, the duration of the pupal period was shorter, even though on pupation all pupae were isolated one per 1-oz. plastic cup.

As one might expect, the pupal weights of crowded larvae were lower; in females, about 35 percent lower, and in males, 20 percent lower. Maksimovic (*1958*) has shown that pupal weight and fecundity are correlated in this species.

The number of additional larval stages in the crowded cultures was higher:

Test	*Larvae with additional instar*	
	Isolated (*percent*)	*Crowded* (*percent*)
1	8.9	23.1
2	39.5	51.7

This increase was obtained even though the level of crowding during instar I, when this trait apparently is induced, was relatively low.

Another interesting result of crowding was a change in the coloration of adults. Unlike the conventional cases of phase polymorphism, the crowded individuals were lighter.

Starvation experiments were conducted to determine if starvation, by extending the length of the 1st instar, could induce an additional molt. Larvae starved during the 1st instar had a significant increase in the number of subsequent molts:

Days not fed	*Larvae tested* (*No.*)	*Additional molt* (*percent*)
1 & 2	130	33.1
3 & 4	138	32.6
5 & 6	141	31.2
Control	141	14.1

Larvae starved in a similar manner during instars II, III, and IV did not show an increase in the number of additional molts. In fact, starvation early in these instars resulted in a consistent trend toward a reduction in the number of additional molts, providing some evidence that this trait is reversible during later instars.

Study of Egg Masses

Although the qualitative change, expressed as an increase in the number of larval instars, can be induced by factors that delay development during instar I, it is of more importance to the population biology of this species that this trait can be induced during the previous generation through the egg (*Leonard 1970b*). To determine the frequency in occurrence of additional molts, a sample of or all of the progeny of 87 egg masses have been analyzed. In each of the 87 egg masses, some larvae underwent an additional molt, with the range in additional molting types from 2.7 to 97.9 percent. This range of difference was not due to differences in rearing techniques, since all larvae were reared individually, on the same diet, in the same controlled room. Thirty-five egg masses had up to 20 percent of their progeny with one or more additional molts, whereas 14 egg masses had over 80 percent of their progeny with one or more additional molts.

It would appear at first that the maternal influence might be a genetic trait, but crossing experiments between different molting forms could establish no tendency for the trait to segregate

as a Mendelian gene, even though Goldschmidt (*1934*) stated that the trait was regulated by alleles of the "T" gene.

Pursuing the egg-additional molt relationship further, I divided six egg masses into equal quarters according to their basal area, from front to rear. The eggs from each quarter were dehaired, then measured with an occular micrometer. Each egg was allowed to hatch, the larvae were reared to pupation, and the number of molts were recorded. Two interesting pieces of data emerged:

- There was a size gradient in eggs, from the front to the rear of the egg mass, with the first eggs laid and the first produced in the ovaries of the females being larger.
- There was a higher percentage of additional molting types in the last quarter of the egg mass.

In four of the six egg masses analyzed, the increase in larvae with an additional molt from the smallest eggs was from just under twofold, to more than a threefold increase. In the two egg masses in which no such trend was observed, the percentage of additional molting types was very high in all quarters of the egg mass.

The relationship of small egg size and the increase in the number of instars indicated that there was most likely a correlation with nutrition of the eggs, since the smaller egg size probably signified a smaller amount of yolk content. About the time that I was completing these studies, Wellington and Maelzer (*1967*) published a paper on the results of their experiments on the western tent caterpillar, treating pupae with farnesyl methyl ether, a juvenile hormone mimic. The developing eggs in treated pupae were deprived of nutrients, and these eggs produced a higher percentage of the sluggish behavioral types, indicating to the authors that the behavioral types in *M. pluviale* are mainly nutritional products. Also, Wellington (*1957*) had shown earlier that the sluggish larvae had a higher tendency to have an additional larval molt.

Differences in Dispersal

To determine if eggs from sparse gypsy moth populations differed from those from dense field populations, egg masses have been fragmented into quarters, and the eggs measured. In the egg masses from the sparse population, the first eggs laid were the largest. In the egg masses from the dense population, the number of eggs per mass was much smaller, and although the same tendency of the first egg laid to be larger is seen, the range of difference in the size of eggs from the first to last portion of the mass was less. Also, the eggs tend to be smaller than those from the sparse field population. The eggs from the dense population were more like those from the last quarter of the egg mass in the sparse population. These eggs have not yet been reared to determine the number of larval instars, but one could predict from earlier work that the numbers of additional molting types will be higher in these eggs than from those of the dense field populations.

I have spent much time establishing that the gypsy moth has a qualitative change expressed in an additional larval instar, but I have not yet indicated what effect this change has on the population biology of the species. The extra-molting types differed in several ways. Any of these differences could have a marked effect on the population biology of the gypsy moth, but I would consider that the most important difference is the prolonged rate of development during instar I. This life stage is perhaps the most critical of all; for after hatching, larvae must leave the egg mass and find suitable food. Of importance to the evolutionary biology of this species is that instar I is the only stage in which dispersal can effectively take place. Female gypsy moths are flightless. The dispersal of larger larvae can be measured in meters, but the spread of newly hatched larvae can be measured in miles.

Any factor prolonging the first instar will enhance the possibility of dispersal—but this is only partially true. It is the behavior of larvae that has the most important impact on dispersal. During instar I, larvae normally remain on the leaves. They spend most of their time on the undersides, and come to the

top surface to feed at dawn after temperatures reach 45°F. (*Leonard 1970*). Larvae return to the undersides of leaves in mid to late morning, and a few will again feed in the afternoon. At night, larvae are on the undersides of leaves. While on the undersides of leaves, larvae are anchored to a sparse mat of silk, and they are not readily dislodged. Also, after their first meal, their weight doubles. These quiescent larvae are not likely to be dispersed, and few larvae trapped on screens have the characteristic appearance of having fed (*Leonard 1967, in press*).

If larvae hatch where there is no food, as on dead trees or other inanimate objects, they become more active as hunger increases. Easily irritated, these larvae are induced to spin down on a thread of silk (*Leonard 1967*). These larvae are readily picked up and dispersed by even a slight breeze.

The larvae that hatch from small eggs—those that undergo the qualitative change—have a longer prefeeding phase, during which they will not settle and feed, even in the presence of suitable food. The prolonged instar I is a reflection of this longer prefeeding phase. In dense field populations, I have collected and released larvae at the base of saplings and recovered only a few (*Leonard, in press*). The larvae climbed the sapling, encountered leaves with no larvae on them, yet continued climbing to the top of the sapling, or the tip of the branches, and were dispersed. These larvae hatched from nutritively deficient eggs showing characteristic signs of hunger. What finally induces such larvae to settle and feed is not yet known.

Dispersal is passive, and few larvae will be deposited where suitable food is available. Those larvae that do survive, because of their additional larval stage, have higher pupal weight and are more fecund. Part of the loss encountered in dispersal is offset by a higher reproductive potential of survivors.

Population Flush

The gypsy moth is characterized by population flushes. These flushes, on the surface, appear to be deleterious, for they ultimately result in dramatic crashes when the food resources

are depleted, and/or epizootics occur. I suggest that these flushes are a necessary event in the biology of the gypsy moth to bring about dispersal and genic mixture. If one can visualize a hypothetical population in an area where suitable host plants prevail, one would anticipate that the population density would increase, with the rate of increase dampened by various biotic and abiotic factors. As the population density increases, there comes a point in a gradation where larvae are stressed, and these larvae produce the females that lay eggs with reduced food reserves.

The larvae emerging from these eggs will not readily settle and feed, but remain in an active state, which greatly enhances their chances for dispersal by wind. Before the population crashes, many larvae will have been dispersed. Thus population flushes can be advantageous to insure dispersal and genetic recombination, and may have evolved with the loss of flight in females. This mechanism of self-regulation provides the gypsy moth with the means of reacting to changing environmental conditions, particularly increasing population densities, both more rapidly and more efficiently than if this mechanism were under strict genetic control and dependent on selection for its expression. This is an important point, one that has been overlooked by many who consider that qualitative changes must operate as Mendelian systems. It is not necessary to select out ninety-nine percent of the gypsy moths to have this functional polymorphism operate.

It would be interesting to know at what density nutritively deficient eggs will be produced during a population flush. I would predict that it is the density at which there is an observable and dramatic shift in the diel periodicity of larval activity. For the first three instars, larvae commence feeding with the first light of morning, as temperatures moderate. At instar IV there is a dramatic shift in feeding behavior: larvae feed during hours of darkness and remaining quiescent during the day. At high population densities, this diel periodicity is upset, and larvae are active both day and night. This shift occurs before there is any obvious lack of available food. I feel that it is these active larvae that are producing the smaller eggs, for they prob-

ably spend less time feeding, and their wandering behavior utilizes food reserves that would normally be deposited in the eggs.

What particularly intrigues me is that all elements of this qualitative change—the deficient eggs, the change in diel periodicity, the change in larval behavior at instar I, and the increase in the number of larval molts—could all be controlled by the same hormonal system, the brain-corporus allatum-prothoracic gland system. Certainly molting is controlled by this hormonal system. DeWilde (*1964*) reviewed work showing that the corporus allatum affects the amount of proteid yolk supplied the trophocytes during oogenesis, and also affects feeding behavior in some insects. Wellington and Maelzer (*1957*) treated pupae of the western tent caterpillar with a mimic of juvenile hormone, and obtained eggs deprived of nutrients.

Can the occurrence of a density-regulated mechanism to induce dispersal be used to effect control of the gypsy moth? I believe it can, by preventing this qualitative change from taking place. Such a strategy would necessitate a completely different approach to control. At present, dense populations are sprayed by air to prevent defoliation. In the post-DDT era, this procedure is not as effective, for the short-residual insecticides don't provide the same protection as did DDT.

During a gypsy moth outbreak, the windspread of larvae creates several problems. Larvae are dispersed to new areas, and most of the spread of this insect throughout the Northeast has been by this means, and the spread westward is hampered primarily by the prevailing winds in the spring. Larvae are also spread in large numbers into the areas adjacent to the outbreak, often into areas where they would not normally occur in troublesome numbers.

Strategy

The strategy I suggest is to monitor gypsy moth populations only in areas of potential foci of epidemics—mainly on the higher elevations. When these populations begin to increase to the point where the qualitative shift and subsequent dispersal would occur, then some means of control would have to be applied.

This would occur while the population was still sparse, before any noticeable defoliation had taken place. Because of this, the whole concept of control would be different, for it would not be necessary to attain a high percentage kill; in fact, it would be disadvantageous, for in a population-management strategy, it would be desirable to maintain as many biotic control agents as possible.

As far as I know, no one has attempted to maintain sparse gypsy moth populations. If such an approach were to be initiated in the near future, it would probably be necessary to use insecticides, for too little is yet known about the use of biotic agents. Many insecticides are not now considered for use because they do not perform well against outbreak pupulations. These insecticides may be useful in a population-management scheme, with the residual population serving as a reservoir of biotic control agents. The areas to be sprayed would be greatly reduced, and the woodlands in the lower elevations would be ignored, because the populations in these areas rarely reach outbreak conditions unless there is a large influx of dispersing larvae.

There are a number of biotic control agents that could be useful in maintaining sparse gypsy moth populations, including parasites and predators. Some of these species might be suited for mass culture for release to suppress gypsy moth populations. There are two diseases that are promising: the nuclear-polyhedrosis virus, and the strain of *Streptococcus faecalis* recently discussed by Doane and Redys (*in press*). Both of these pathogens have given encouraging results in field applications (*Rollinson et al. 1965; Doane in press*).

The sterile-male technique, which has apparently been hampered by rearing problems, has not yet been tested adequately.

The sex pheromone of the gypsy moth female provides several novel alternatives for control.

None of the biotic control agents has been noted to provide adequate control, but they were expected to perform against epidemic populations, where numbers of gypsy moths were often so high that a small percentage of survivors could still cause defoliation. In a population-management approach to control,

defoliation will not be a concern, and abiotic agents, either singly or in concert, could provide a means of preventing outbreaks.

In summary, the quality of insects comprising populations may be an important factor in the biology of that population. In the gypsy moth, qualitative changes occur primarily as a response to increasing density, and appear to be characterized by a nutritive change affecting the physiology of the insect, particularly the hormonal system. A major response to the qualitative change is an increase in dispersal. Such a density-regulated mechanism to induce dispersal can operate more rapidly and efficiently than one with direct genetic links that depends on selection for its expression. Preventing such a qualitative change by maintaining populations at sparse levels may make it possible to prevent widespread epidemics. Such a strategy would necessitate a change in the current concepts of pest control, and would require a thorough knowledge of the population biology of both the target insect and the biotic control agents.

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VERTEBRATE PREDATORS

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THE ROLE of small vertebrates as predators of forest insects has not been widely studied. Nonetheless, in those instances where this aspect of the population dynamics of forest insect pests has been examined there is substantial evidence that further investigation would be profitable. To appreciate fully the role of vertebrates in an integrated control system, we first of all should examine the role of vertebrates in the forest ecosystem. Next we should examine their impact upon insects of economic importance. And finally we should examine means of employing the knowledge gained into meaningful integrated management schemes. I use the word vertebrates synonymously with only the higher taxa; in other words, birds and mammals.

Vertebrates in the Forest Ecosystem

When we examine the vertebrate fauna of a forest system as predators on forest insects, we can reduce a vast array of taxonomic groups to a few dozen. Of the birds, the forest entomologist would be interested in the wood warblers, the fringilids, and the woodpeckers. Among the mammals, he would be interested in the insectivores and rodents. And it would be only fair to point out that these groups bear relationships on both the plus and minus sides of the ledger; for although they do destroy forest insects in significant numbers, some of their other behaviours tend to counterbalance the beneficial effects of their predatory habits. For example the woodpeckers, although they destroy prodigious numbers of noxious insects, also drill tap holes that injure trees and damage forest products. And rodents that in general are surprisingly efficient insect predators, also de-

stroy seeds, seedlings, and saplings that could extend the economic benefits of the forest.

Unlike the parasitoids that usually have a relatively restricted range of types of prey, most forest vertebrates consume a wide array of food material. They are also in general highly discriminate in their choice of foods, and their choice may not always be in the interests of control of a specific noxious pest. On the other hand, they may respond to population increases of a specific insect to the advantage of the forest manager.

For example, when abundant, the spruce budworm forms a significant component in the diets of many forest birds (*Morris et al.* 1958), and the larch sawfly is fed upon almost exclusively by certain small avian predators during periods of abundance (*Buckner and Turnock 1965*). This response very frequently continues below the level of the effectiveness of certain parasites, which has prompted Morris and associates to point out that at low levels of budworm populations it may in fact be the vertebrate portions of the forest fauna that are exerting the controlling influence upon this insect.

In the sawfly-infested bogs of southern Manitoba it has been shown that the larch sawfly is a preferred food of many of the small mammals inhabiting the ecosystem and that their predation often is the most significant of all biological control elements within the system (*Buckner 1966*). Alternatively, however, it has been pointed out that there are indeed very few vertebrate predators of insects such as the forest tent caterpillar and the gypsy moth, both of which appear to have strong defences against possible predation by vertebrate predators (*Buckner 1966*). These defences presumably are olfactory and tactic in nature and tend to reduce the effectiveness of a potential vertebrate predator population. Data about this are very scarce, and what is required is a much wider description of the foods and feeding habits of as many vertebrates in the ecosystems that are of interest to us as we can manage to assemble.

Selective feeding behaviours of small forest vertebrates play an important role in their ultimate role in the population dynamics of any insect. We should take care to assemble as much information as we can on this interesting aspect of our problem.

For example, many birds are known to avoid diseased insects. Some diseased insects are obviously unpalatable to avian predators. Others, having been attacked for example by certain parasites, become so irritable that they make difficult targets for avian predators. Thus larch sawflies that have been discoloured by disease or those that exhibit the thrashing movements of irritability following attack by parasites are rarely consumed by small warblers and fringilids that are foraging amongst the branches. And in the realm of small mammalian predators of forest insects there is now considerable evidence that many insects that have been attacked by parasites are no longer palatable to small mammalian predators. Mammals tend to reject larch sawflies parasitized by diptera and disease to a greater extent than those parasitized by hymenoptera.

In addition to the direct effects of attack by vertebrates on insect individuals, there are also subsidiary feeding behaviours which tend to increase the predation pressure upon an insect population. For example, certain birds feed only upon a portion of their insect prey (*Buckner and Turnock 1965*). Certain sparrow predators of the larch sawfly decapitate the larvae and feed only upon the head. Some of the grosbeaks decapitate their larvae and feed only upon the thoraxic portion. Other predators break their prey in two and consume only a part, and still others destroy their prey without ever feeding upon it.

Small mammals also exhibit subsidiary feeding behaviours. For example, shrews kill insects apparently for the sport of it. Most mammals gather and hoard large quantities of insect prey to feed upon later when most prey are unavailable in their natural state. There are, of course, some counterparts of this in the attacks of invertebrate predators and parasitoids of forest insects. For example, certain hymenopterous parasites sting without ovipositing; and stung prey, because they usually die, are destroyed in a subsidiary manner. Frequently destruction of prey through the subsidiary processes are of greater importance than attack for the satisfaction of basic food requirements. Insects such as the larch sawfly suffer more through the effects of subsidiary feeding behaviours than they do to satisfy the basic food requirements of their predators (*Buckner 1966*).

The numerical strength of predators is also of importance in determining their relationships in the population dynamics of forest insect pests. It is only rarely that small forest vertebrate populations are closely tied to the population abundance of insect prey. Small vertebrate populations are more frequently linked with complexities in the biological ecosystem.

For example, breeding populations of small song birds are almost assuredly limited by their territorial behaviour. An upper limit may be reached far below the carrying capacity of the environment in which they exist. Certain small mammals such as the aggressive shrews also exhibit territorial behaviour, and the upper limit of their breeding populations are almost certainly limited by this factor. Available nesting sites both for small mammals and birds also form an important component of the population dynamics of these groups.

There is, however, a response by small vertebrate predators that may be directly related to the numerical strength of the prey. This is effected through behavioural responses rather than by strictly breeding ones. There are many examples of small vertebrates aggregating in areas where prey densities are high. Elton (*1942*), for example, describes a congregation of tawny owls moving into an area in which voles have increased in numbers; and of course the control of the mormon cricket by gulls is a striking classic example of a behavioural numerical response.

In the realm of forest insects there are also a number of examples. Blais and Parks (*1964*) have indicated that residual populations of the spruce budworm have been almost certainly controlled through the predatory actions of the grosbeaks that have invaded the remaining pockets of infestation after insecticide treatment; and Buckner and Turnock (*1965*), working on the larch sawfly, have demonstrated quite clearly that birds that do not normally inhabit the bog ecosystem range into the bogs for feeding in times of larch sawfly abundance. There is also evidence that small mammalian cocoon predators invade the bogs from upland sites when large numbers of cocoons are forming in the late summer.

These examples, although not fitting the classic idea of nu-

merical responses, are nonetheless effective numerical responses in the population dynamics of a particular pest species; and, it has been pointed out, many of these responses are of greater significance in the population dynamics of the pest than are the classic breeding responses as first outlined by Solomon *(1949)*. For the pest insect it matters very little whether the response has arisen through breeding or through an aggregation of independent individuals moving into the area to feed on an abundant prey.

The Impact of Vertebrate Predation

Reliable estimates on the impact of small vertebrate predators on populations of forest insect pests are very rare indeed. This factor has been neglected in sophisticated analyses on the population dynamics of the major pest insects. However, a few examples indicate that there is promise in this line of investigation.

The studies of R. F. Morris *et al. (1963)* on the spruce budworm populations in central New Brunswick undoubtedly provide the best long-term continuing records on this aspect. Morris and associates have assessed populations of small mammals and birds in budworm-infested stands for almost two decades and have concluded that, in general, small mammals play an insignificant role in the dynamics of budworm populations, but that considerable importance may be attributed to the role of small birds as predators of this insect, especially at low insect densities. Morris *et al. (1958)* have considered small birds as possibly one of the major controlling factors at endemic prey levels. Watt *(in Morris 1963)*, deriving his information from Morris' long-term data, also advocates that birds may be of considerable importance in cleaning up residual populations of the past after the major outbreak has run its course. These data are substantiated by Blais and Parks *(1964)*.

Neilson and Morris *(1964)*, working on the European spruce sawfly, have also attributed vertebrate predation as a key factor in the population dynamics of this insect. Small mammal predators acting upon the cocoon stage are probably the most important controlling factor of this insect.

In independent studies of winter moth population fluctuations, Embree *(1965)* in New Brunswick and Varley and Gradwell *(1962)* in England concluded that small mammals preying upon the pupal stages of this insect can be a very important population mechanism indeed. The Canadian studies have indicated that small mammals—particularly shrews—are likely to play an exceedingly important role in the population dynamics of this insect, but that their depredations are overshadowed by insect parasites, which in this particular pest insect account for a higher proportion of mortality than do small vertebrate predators.

Essentially the same situation occurs in the winter moth infested oak forests in Britain, where Varley and Gradwell arrived at similar conclusions except that the extent of mammalian predation is somewhat higher than the situation in Canada and the insect parasites somewhat lower. However, on this insect, control is very likely effected by the combination of both factors, and the balance is attributed primarily to invertebrate control measures rather than small vertebrates.

Similar studies on this insect in the USSR *(Korol Kova 1963)* have indicated that small song birds are important predators of this insect and could account for a considerable proportion of the total mortality. Many of the Russian workers attribute a greater importance to the role of small avian predators than they do to small mammals. Chief among the mammal predators both in Europe and Asia and in North America are the shrews, and these account for considerable numbers of winter moth.

MacLeod *(1966)* and associates, working on the jack pine sawfly in Quebec, have investigated the role of small mammals as cocoon predators. This research team has attributed considerable importance to the predatory effects of small mammals, particularly shrews. They have noted that vast quantities of sawfly cocoons have been destroyed by these small predators and that this may be a key factor in the dynamics of this insect.

The team approach to study of the larch sawfly in central Manitoba has taken into consideration the role of small vertebrates in the population dynamics of this insect. Continuing records of small vertebrate populations on a number of the perma-

nent study plots now range back almost two decades. It has been concluded from the analyses of these population data that small song birds, as in the case of the spruce budworm, may be of considerable importance in the population dynamics of the larch sawfly. Their importance is likely greater at low than at high insect population densities.

There are several striking responses to the prey population when it reaches higher densities, however; and these are affected through large numbers of avian predators invading the bogs and destroying large quantities of insects. In general, one must conclude that their effect is greatest at lower insect densities. Studies on small mammals concurrent with those on birds, and reaching back in the continuum several years farther, have indicated that these are likely the most important population decimating agent acting against the larch sawfly in this area.

The effects, however, are exceedingly erratic. At some times mammals destroy large numbers of the cocoon population, and at others they destroy relatively insignificant numbers. This erratic effect produces erratic fluctuations, and it must be concluded that mammals in general certainly are not the perfect key factors that one would have hoped for. However, they do serve as important subsidiary population-controlling mechanisms and should be considered seriously in management programs.

The Integrated Approach

In considering small vertebrates in insect pest management programs, one must point out that to date no real integrated approach to control, specifically using small vertebrates, has ever been attempted. The remarks that follow therefore represent a few ideas as to how one might consider these in an overall control program. I would like to bring forth as the example the effect of mammals and birds as predators of the larch sawfly.

The most important single group of vertebrate predators of the larch sawfly are the shrews. There are six major insectivore predators of the larch sawfly in the tamarack bogs of southeastern Manitoba. These are the cinereus shrew *Sorex cinereus*, the saddle-backed shrew *Sorex arcticus*, the water shrew *Sorex*

palustris, the pigmy shrew *Microsorex hoyi*, and the short-tailed shrew *Blarina brevicauda*.

These six species occur in varying numbers and in varying microhabitats within stands infested by the larch sawfly. The most catholic in distribution is the cinereus shrew which ranges from the central water edge well up to the upland sites. The most restricted is the water shrew, which is confined principally to the fringes of the water areas. The others to a greater or a lesser degree range in limited areas throughout the remainder of the habitat. The saddle-backed shrew inhabits the deeper yet drier areas of the bogs. The pigmy shrew occupies the transitional zone between bog and upland. The short-tailed shrew, principally an upland species, invades to some extent the drier areas of the bog. From the standpoint of numbers, we can consider only four of them as important predators: the cinereus shrew, the saddle-backed shrew, the pigmy shrew, and the short-tailed shrew. The cinereus shrew is most important of all.

The cinereus shrew and the pigmy shrew consume the largest quantities of insect material. The cinereus shrew indeed feeds almost exclusively on the larch sawfly during periods when the insect is abundant. Curiously, however, the cinereus shrew feeds principally on larvae extracted from the cocoons; whereas the pigmy shrew feeds more on adult insects and hence destroys larger quantities of adult insects. The saddle-backed shrew, although it has a larger appetite because it is larger, consumes a smaller proportion of insect material; it feeds both on larvae and on adults. The short-tailed shrew, although almost half its diet consists of insect material, is not a particularly important predator of the larch sawfly because the sawfly accounts for only about 15 to 20 percent of its total diet.

The selectivity of the various shrews also bears importance. For example, the cinereus shrew rejects cocoons that have been attacked by fungus, by decay, or that have been attacked by dipterous parasites. When selecting parasites for release against an insect such as this one, one should, all other things being equal, favor dipterous over hymenopterous parasites because of the selective feeding behaviour.

In the propositions so far put forward to control the larch

sawfly, one of the most promising proposals has been a treatment whereby the water table in infested stands is manipulated. The principle behind this is that, when cocoons are newly formed or are going into the transition in forming adults, they are extremely susceptible to inundation. Thus if we were able to flood newly formed cocoons or cocoons that were in the process of transforming into adults, perhaps we could effect good control. This may also effect the shrew populations, for the saddle-backed shrew requires a relatively deep water table whereas the habitat requirements of *Sorex cinereus* are considerably less restrictive. Thus we could not only favor selection of a desirable shrew species, but also could couple this with a very devastating inundation of the developing cocoons.

By raising the level of the water table we would at the same time favor the more desirable cinereus shrew; and if such a flooding operation were effected during a period at which the shrews were reproducing, this would increase the possibility of favoring cinereus and at the same time decrease the abundance of the less desirable saddle-backed shrew. And if at the same time we could lower the water table at a time when sawflies are falling from the trees, we could perhaps increase the population of the saddle-backed shrew to take advantage of its larger appetite. So by careful manipulation of the water table we might not only effect the devastating direct blow against the sawfly but couple this with a heavy impact from shrew predators.

Under circumstances in which a chemical control might be considered, we should also be cognizant of the toxicity of the proposed chemical treatment to small forest vertebrates. Certain chemicals are more toxic to small rodents than they are to small insectivores. The choice of a chemical could increase the chances of impact upon the forest pest by decreasing the rodent population, thus allowing an upswing in the insectivore population, which would then add its impact to that of the chemical on the pest insect.

So far, I have considered only the insectivore component of the vertebrate system, but there are a number of other small vertebrate predators that could be effective. Of the other mam-

mals in the system, the small red-backed vole, *Clethrionomys gapperi*, is not only the most numerous but also the most insectivorous. Depredations by this species certainly augment the impact effected by the shrews. Both the cinereus shrew and the red-backed vole hoard cocoons and consume them later when food is scarce. The response of the shrew resembles the disc curves described by Holling (1959), whereas the response of the rodent is more complicated, rising to a maximum but then decreasing again at the higher densities. The effectiveness of such an impact has a relatively narrow range.

And finally, the avian component of the predator system is also important. Spring breeding populations, particularly of the warblers, establish and stabilize relatively early; and the later seasonal fluctuations probably represent increment and migratory movements. Weak numerical responses to gradients of the pest populations are evident, but the greatest numerical responses are behavioural ones. Most of the bog-inhabiting or bog-foraging avian species are effective predators of the target insect, but some feed primarily on larvae, others principally on adults, and still others about equally on both.

So in considering an integrated approach and evaluating the small vertebrates concerned with such an approach we should consider first of all the type of predator that we wish to encourage. Surely we want one with a high feeding capacity, one that has a preference for the target insect, one that is reticent to feed upon insects attacked by other natural control agents acting against that insect, one that maintains high population densities, one that can respond quickly to other control measures applied simultaneously, and one that will be relatively unaffected by subsidiary treatments. One example of such a predator is certainly the cinereus shrew, and it is significant that this is one of the first vertebrates ever to be experimented with for controlling a forest insect. The case I am referring to is, of course, the introduction of *S. cinereus* into Newfoundland to add to the biological control complex of the larch sawfly (*Buckner 1966*). The shrew now occupies much of the island and causes a significant impact upon the pest insect.

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INVERTEBRATE PREDATORS

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OF THE TWO WORDS that comprise my subject, each in a different way presents a problem. Zoologically the *invertebrates* include about every animal organism that cannot be classified as vertebrate. However, for purpose of discussion my comments will be restricted to arthropods and more specifically to the classes Insecta and Arachnida. The term *predator* is no less troublesome, for it is virtually impossible to accurately categorize the trophic behavior of many invertebrate species. Though it would be convenient to pigeonhole each species as phytophagous, parasitic, predacious, saprophytic, etc., this becomes a practical impossibility in the face of dietary habits that change from one life stage to another.

For example, what is one to do with a species such as *Itoplectis conquisitor* (Say). This hymenopterous insect develops as a pupal parasite of the gypsy moth. However, the adults may kill and feed on body fluids of as many as 250 pupae for each pupa successfully parasitized (*Campbell 1963*). When not stinging host pupae for feeding or oviposition, the adult female will feed, together with the adult males, on aphid honeydew and flower nectar.

The number of species exhibiting this type of parasitic behavior is very large. One family alone is estimated by Townes (*1970*) to contain 60,000 species. This would of course be the Ichneumonidae. Many years ago Wheeler (*1923*) coined the term *parasitoid* and applied it to these insects, which he regarded as not true parasites, but as extremely economical predators. Although in the past not generally accepted by entomologists, the term now seems likely to come into common usage. With

the resurgent interest in biological control, there is need for a term that can be applied to the parasitic insects that will not convey the more restricted connotation and often opprobrious meaning of parasite.

However, the introduction and use of the term parasitoid points up my problem in discussing invertebrate predators. If I am to talk about the significance of predation by one insect on another, I can scarcely overlook the predatory activity of a very large number of parasitoid species.

Few people with any degree of familiarity with insects fail to be impressed by their remarkably diverse feeding habits. Certainly almost any conceivable dietary habit or combination of habits will be exhibited by one or more species of insect. However, I question whether even entomologists fully appreciate the extent to which the predacious habit pervades the insect world. If we were to list all orders, families, tribes, and genera of Insecta and Arachnida containing species that are predacious in some life stage, few groups above the tribal taxon would be omitted.

When we view invertebrates in terms of number of kinds and diversity of habit, it is obvious that a really conscientious treatment of invertebrate predators could profitably occupy much more than my allotted time. Therefore I propose to speak in generalities and to venture little more than some opinions regarding the role of predators in the population dynamics of prey species.

The Terms

So there be no misunderstanding about my use of terms when referring to different habits of insect groups, I will comment on distinctions between the terms *predator, parasitoid,* and *parasite.* Most people will agree that a predator is an organism that normally kills a more or less large number of serially contacted and consumed prey organisms. A parasite by contrast will live most of its life permanently attached to a single living host.

Unfortunately, the above definition of a parasite ill describes the behavior of most parasitic insects. Many species commonly

referred to as parasites actually develop in hosts that are either killed by the parent parasite or die at some point in the development of the invading organism. Such parasitic insects are also usually free-living in the adult stage and in this stage may behave as predators.

Therefore, in further discussion of the importance of predators as compared with parasitoids and pathogens, remember that predacious activity of parasitoids will contribute to the functional importance of predation.

As indicated earlier, my principal objective is to consider the respective roles of predation, parasitism, and disease in regulation of host populations. Ultimately the question becomes one of knowing how these agents are to be manipulated for the purpose of holding pest populations at or below economic thresholds.

In 1929 W. R. Thompson wrote that though insect predators are numerous and are generally acknowledged to be beneficial, they are by no means universally believed to be as useful and important as insect parasites. Thompson then proceeded to present his reasons for believing that the part played by predacious insects was under-estimated. He argued that the relative importance of these two types of controlling agencies in any given case could be decided only by careful investigations in the field. Despite the recent life-table studies and mathematical models of R. F. Morris (*1963*), K. E. F. Watts (*1959, 1963*), C. S. Hollings (*1959, 1963*), and others it is my impression that our understanding of the relative role of predators in regulating pest populations has not advanced greatly beyond that of 1929. Perhaps it would be more correct to say that our ability to modify ecosystems through manipulation of predator populations has not advanced appreciably.

Though I make no pretense of being an active research worker in this field, I have for some 10 years now been involved in one way or another with biological-control programs. As a result of recent developments with which you are all well acquainted, biological control has suddenly moved from an almost stagnant backwater into the main current of research on pest control. Questions that could once be safely relegated to the

ivory tower are now being hotly debated even in the popular press. Program-management people are finding such questions relevant and are pressing research personnel for answers that will not be immediately forthcoming.

Among the questions for which answers are needed, one of the most important is that of the relative values of the three major categories of natural enemies. If predators, parasitoids, and pathogens play different roles in regulating host populations, we must know what these roles are and how each can be used to the best advantage in the strategy of pest management. As a result of my own field experience and general familiarity with entomological research, I am convinced that invertebrate predators are very much more important than is generally realized. In fact I think there is good reason to believe that they constitute our first line of defense against the onslaught of insect pests.

The Value of Predators

Certainly we have examples that amply illustrate the potential value of predators. The first and most publicized example of biological control, the cottony-cushion scale, was accomplished by a predator—the vedalia beetle. Another coccinellid (*Cryptognatha nodiceps* Marshall) has controlled coconut scale (*Aspidiotus distructor* Signoret) in Fiji (*Taylor 1935*) and Principe (*Simmonds 1959*). A different kind of predator, the mirid bug *Cyrtorhinus mundulus* (Breddin), controlled the sugar cane leafhopper *Perkinsiella saccharacida* Kirkaldy in Hawaii (*Pemberton 1948*).

There are many well-documented cases of population release among previously innocuous plant-feeding species of insects and mites following use of organic insecticides. This is generally attributed to destruction of both predators and parasitoids. Evidence of this was reported by Hoffmann et al. (*1949*), who noted massive outbreaks of the mite *Paratetranychus ununguis* (Jac.) and several species of aphids in a Pennsylvania forest experimentally treated with DDT in 1945. They attributed these outbreaks to elimination of the abundant mite predator *Coniopteryx vicina* Hagen and drastic reduction of such aphid pred-

ators as *Anatis 15-punctata* (Olivier) and several species of syrphid flies.

Later examples of secondary pest problems that have followed in the wake of DDT and similar highly effective insecticides are too numerous and well known to warrant citing here. The likelihood that these problems have been precipitated in great part by the destruction of natural enemies is indicated by excellent experimental evidence. Perhaps the most convincing of the experimental studies are those of Franz (*1958*) and DeBach (*1955*). Franz was able to demonstrate highly significant increases of the balsam woolly aphid, *Adelges piceae* Ratz, in "plot" areas of tree trunk from which predators were excluded. DeBach used the insecticidal check method and concluded that DDT residues had no direct or indirect benefical effect on a diaspine scale population except through selective elimination of parasitoid *Aphytis chrysomphali* (Mercet). It is also well known that many scale insect and aphid outbreaks result from ants protecting them against predators and parasitoids (*DeBach, Dietrick and Fleschner 1951*).

From these various lines of evidence I believe most people are now willing to agree that natural enemy populations constitute a valuable stabilizing influence in ecosystems and are important factors in control of many pests. However, there is no general agreement about, or great interest in, the relative importance of predators, parasitoids, and pathogens as separate components of the natural enemy complex. Such comparisons as have been made have, for the most part, concerned the comparative ability of individual species to control pest populations. Any assessment of the value of predators as opposed to parasitoids or pathogens has consisted of little more than a tally of pests controlled by one as opposed to another. It is important that this question be investigated, for it may have great bearing on how natural enemies are managed.

Three Approaches

On the basis of present knowledge, there are three possible approaches to the use of predators and parasitoids for pest control:

1. The introduction of effective enemy species into niches where there are unexploited or inefficiently exploited food resources in the populations of pest species.

2. Modification of the environment to provide conditions favorable for increase of enemy species already present and able to exploit the pest populations.

3. The mass-production and inundative release of species capable of feeding on and destroying pest populations before they cause economic damage.

Of these approaches the first two impress me as the most practical and in the long run the least expensive. This is particularly true of pest problems associated with the forest habitat. Many of you know of the work that is being done in Europe and the USSR to utilize ants for control of certain forest pests. A summary of the European literature on this subject was published by G. Cotti in 1963. Other important references are one by K. Gösswald, G. Kneitz, and G. Schirmer in 1965 and an evaluation of the European research on use of red wood ants for protection of forests published by K. G. Adlung in 1966. That similar use of ants is being made in the USSR is indicated by papers published in the proceedings of a 1964 Symposium on Biological Control of Agricultural and Forest Pests edited by A. I. Cherepanov.

In Italy, under the direction of M. Pavan, extensive efforts have been made by the ministry of Agriculture and Forestry to relocate colonies of *Formica polyctena* Foerst in pine forests. As a result of a census conducted by 1,500 agents of the Italian State Forest Corps, Pavan (*1959*) calculated that in the Italian Alps there were more than 1,000,000 nests of four species of *Formica*. He estimated that these nests contained 300 billion workers that would destroy 14,400 tons of insects during an annual activity period of 200 days.

In Germany Gösswald (*1940*) has developed techniques for mass-breeding queens of *Formica rufa* F., and he has investigated the economic value of these ants. He has also actively promoted the colonization of ants in many forest situations for

control of sawflies and lepidopterous pests. Ant hills are protected by law in Italy, Switzerland, and Germany; and I have been told by a German colleague that our military forces in Germany are billed for each ant hill destroyed in the course of maneuvers or other activities.

In Russia, Smirnov (*1964*) recommended that hills of the genus *Formica* be moved from forests that are being cut and placed in new plantations. Marikovskii (*1964*) noted that it was futile to move colonies to forests where competing species of ants were already well established. He urged that until more information was available and better success obtained from efforts to colonize the red wood ants, first priority should be placed on protection of existing colonies by means of State regulations and public education.

Adlung (*1966*) noted in his review clear evidence that ants are of value in controlling the common European forest pest *Panolis flammea* (Schiff.), and that the species *F. polyctena* has a certain limited value in pine forests. He concluded that establishment of nests is of no value in spruce plantations and would be injurious in beech forests, where the ants would protect and promote outbreaks of aphids that in turn cause the trees to be attacked by a canker fungus. He also noted that a considerable part of the ant's prey consists of beneficial insect species. Hence it may be concluded that ants are not an unmixed blessing even in situations where they do exercise effective control over pest populations.

An Appalling Task

There are of course many other examples of manipulation of predators, most involving movement of species from one country to another. In view of the number of pests that have invaded new continental and insular areas as well the certainty that predator species in many areas could be replaced by more efficient species resident in other areas, there is no doubt that much can be done to alleviate pest problems through introduction programs.

However, as a one-time taxonomist who has had some experience with insect ecology and its applied phase, biological con-

trol, I am appalled by the magnitude of the task that confronts entomologists if we seriously undertake to find and intelligently utilize all the invertebrate predators that are of potential value. There are thousands of species, a very large number of which are not even known to systematic entomologists. We need to know where to find these species and to know details of their life cycles, their ecological requirements, and what we might call their performance specifications. This boils down into a vast inventory job, supported by an information storage and retrieval system that would enable us to quickly determine what species of predator is available and capable of controlling a pest at a place where control is desired. In my opinion our present resources are totally inadequate to meet such a challenge.

The second approach is one that is almost equally formidable. It would require changes in agricultural practices and silviculture on a scale that would require many years if not decades to accomplish. At present we can only guess at what is possible. It is also questionable whether, in the face of the demands for food and space for our human population, the method would be economically feasible. Basically this approach constitutes the most important element of what is being referred to as integrated control or pest management. Although much talked about and experimentally demonstrated to be effective in California (*Stern et al. 1959*) the method has been purposely applied in only a few places and then on a limited scale. The most outstanding of these are applications in Nova Scotia against apple pests (*Pickett et al. 1958*) and in Peru against cotton pests (*Simon 1954*) and cocoa pests in Malaysia (*Conway 1969*). However, the dates of the first two suggests that there has been no great rush to put into practice what has been loudly preached in recent years.

The third method is one that offers promise of being effective in dealing with at least some pest problems. In the case of certain high economic return crops it may prove feasible to control pests by inundative or innoculative release of suitable predators. I am aware that most past efforts to use this technique have been unsuccessful. However I am encouraged by the results of a 1968 experiment conducted in Texas by R. L. Ridg-

way and S. E. Jones (*1969*). In this experiment two field releases totaling 292,000 *Chrysopa carnea* Stephens larvae per acre reduced the populations of *Heliothis zea* (Broddie) and *H. virescens* (F.) by as much as 96 percent and increased the yield of cotton in the test plots threefold. However, a word of caution is in order. The practical application of this method, even for control of *Heliothis* on cotton, will require extensive research on timing of release, numbers required, and most of all upon development of efficient and economical methods of mass-production and distribution of the predator.

Opportunities

I hope my comments will not be construed as presenting an unnecessarily pessimistic picture. Even with our present resources there are opportunities for significant progress toward solution of at least some of our pest problems through manipulation of predators. Furthermore, there is reason to believe that, within an ecosystem, predation acts as one of the most important factors in maintaining stability of the system. There are several lines of evidence suggesting that this is the case.

As a group, predators tend to be less specific in their food habits than parasitoids. They are less dependent upon a single food resource and are better able to maintain stable populations that tend to exploit prey species in proportion to their relative abundance. They also tend to be longer-lived and less likely to be adversely affected by physical factors of their environment. Their searching capabilities are generally greater, and in cases where a predator tends to be specific in its food habits there is likely to be a compensatory increase in either its fecundity or in its searching capacity. These are all characteristics that make predators well suited to play a specialized role in the regulative processes that restrain prey populations to levels below the carrying capacity of their habitat.

Nicholson (*1933*) Utida (*1955*) and others have experimentally confirmed the mathematically derived conclusion that interaction between a host and a parasite within a closed system results in population fluctuation of each species in oscillations of

ever-increasing amplitudes to the point of mutual extinction. That such extinction rarely if ever occurs in nature is attributed by Voûte (*1951*) to the delayed-density-dependent action of predators. This action dampens the oscillations otherwise inherent in the host-parasite relationship. The direct effect is not so much on the prey population, but rather is due to intervention in the relationship between the prey and its parasites. The result is that the populations of both prey species and parasite are regulated at a more or less stable level. Voûte referred to this as "the quenching principle."

More recently Flanders (*1963*) has studied the interactions of food, prey, phytophage, predator, parasitoid, and pathogen components of an ecosystem. Within his system, Flanders found it necessary to introduce shelters that provided the phytophage a degree of protection "above the threshold of security" in order to maintain stability. This is clearly an example of Voûte's "quenching principle," and it introduces the element of space and shelter into population dynamics. However, of special interest to me was Flanders' evidence that disease epizootics occurred in his system followed elimination of the predator by periods of starvation due to host scarcity.

This sets the stage for what I suggest is a plausible and potentially useful classification of phytophagous arthropod populations and their associated natural enemies. In the tabulation that follows, populations are arranged in the order of four levels of abundance reflecting progressively increased density relative to carrying capacity of the habitat. The dominant regulative factor characteristic of each level is also shown:

Class	*Effect on ecosystem*	*Regulating factor*
1	Harmonic	Predators
2	Intrusive	Parasitoids
3	Disruptive	Pathogens
4	Catastrophic	Food

Though the above classification is grossly simplified, it is consistent with a very large body of empirical evidence derivable from the literature and experience of economic entomologists. However, examples will immediately come to mind that would seem to refute validity of such a classification. Perhaps the most striking is that of the Japanese beetle, *Popillia japonica*

Newman, a pest that is now generally believed to be regulated over large areas at a non-economic level by the pathogen *Bacillus popilliae* Dutky (*Fleming 1968*).

I regard the Japanese beetle as an exception that will tend to support the rule. Here the "quenching principle" function is provided by the characteristic habitat of the beetle larvae. The soil in which the larvae live provides a habitat in which the long lived *Bacillus* spores accumulate to a point where probability of non-infection is so high that few larvae survive to become adult. Obviously there are many other exceptions of a similar nature as well as examples that will doubtless exhibit almost every conceivable combination of two or more regulative factors working in conjunction. However, as a generalization that might serve as a useful guide for planning the strategy of biological control and pest management, such a classification could be most useful.

In any event I would urge that greater attention be given to the research on factors responsible for regulating non-economic populations. In the past entomologists have spent a disproportionate amount of time studying threatening or outbreak populations. We know little about what is happening to pest species during intervals between outbreaks or in areas where they are non-economic. If the role of invertebrate predators is a regulative factor responsible for restraining phytophagous insect populations to a harmonic part of their ecosystem, it would follow the biological control experts should place highest priority on the protection and augmentation of predacious species.

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PATHOGENS

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MANIPULATION OF THE environment of insect species often results in the species becoming a pest. There are many examples of this, such as monoculture of crops and forests.

Most species of insects are very adaptable, so that the least disruption of the general environment may cause great changes in population densities. The changes may be either increases or decreases. An increase in population is observed more often because it may be manifested by an increase in damage to a crop. A decrease in population may go unnoticed, but it may be ecologically important to know the causes of the decrease.

Crop losses are usually money losses; so attempts are made immediately to control the pest. Several routes may be followed, but the easiest (and least expensive) is the application of chemical poisons. The use of chemical poisons has been the main means of controlling most insect pests during the last 25 years. The construction of a spray-calendar has been the main occupation of most entomologists because use of chemicals was, and still is, the cheapest, simplest, and easiest way to ensure farmers minimum crop loss to insect pests.

Because it is the easiest, cheapest, and simplest, it is not necessarily the best. The best of anything usually costs more, so we should be careful not to introduce control practices that may provide questionable long-term esthetic, financial, and monetary returns. We know we should be managing our renewable resources more efficiently, particularly in the face of ever-increasing people populations; but policy changes are complex and difficult to effect.

The forest industries of this country are probably leading in this respect because detailed plans for management of large tracts of forested land must be approved by appropriate control agencies. There is a positive effort to provide increased supplies of wood on a sustaining basis without unduly disrupting the environment. A similar approach will eventually have to be developed for many of our food commodities. The agriculturist should be turning even now to the forester to set the patterns for the management of renewable food resources. The principles in both areas are essentially the same in that we are dealing with organisms growing on the surface of the earth.

The ecosystem is not *ad infinitum* as may appear on superficial examination. Individual organisms differ in size, form, etc.; but there are many more similarities than once was thought. We might say that the systems are so highly integrated that one influences the other either directly or indirectly. We must not overlook this principle when studying insect populations or recommending control procedures. Indirect long-term effects may be more important to society than apparently good short-term, monetary, and esthetic returns. This is the approach we are advocating in the study and utilization of pathogens of insects for the suppression and regulation of pest populations.

For best results we should have complete knowledge, but we should be able to make better and better decisions as we gather more and more data. The decisions we have to make should determine the kinds of data we obtain. In the case of pathogens, we know that viruses, bacteria, fungi, protozoa, and nematodes cause disease in insects, including many species that are regarded as pests (*Steinhaus 1949*). In many instances, pest population declines have been associated with disease outbreaks or epizootics (*Balch and Bird 1944*; *Bird and Elgee 1957*; *Bergold 1951*); and there are several examples of the successful dissemination of pathogens for the suppression of pest populations and even the artificial initiation of epizootics (*Briggs 1963*; *Bucher 1958*; *Dutky 1959*; *Heimpel and Angus 1960*; *Steinhaus and Thompson 1950*; *Clark and Reiner 1946*; *Stairs 1964*). However, the practical use of pathogens for pest control and population regulation is in a very early stage of development.

Information Needed

Information concerning the qualitative incidence of pathogens is being collected, but very few studies of a quantitative nature have been made. Even the commercially developed bacterial preparations known as Thuricide etc., have not been used extensively, except by highly trained professional entomologists. These preparations are effective against many lepidopteran pests when used according to the directions on the label, but for several reasons they have been used at only a nominal rate. One of the reasons is that they are slightly more expensive than most of the chemical poisons. There is a clear need for extension entomologists to recognize the usefulness of the bacterial preparations and promote their use more widely and forcefully. There seems to be a strong tendency for many extension entomologists to avoid recommending pesticides that do not carry a chemical name; thus, before pathogens are liable to be accepted, a re-education of entomologists will be necessary.

The efforts toward establishment of a clean environment will assist the development of better ecological utilization of natural controlling or regulating factors, including pathogens, in the management of insect pests. In this regard, we should be gathering appropriate ecological data of a long-term and predictive nature, at least on our present insect pests. Often bits of information are collected by several different investigators. Sometimes the motive for collecting the data is simply interest; and when interest wanes, the investigator may explore another, perhaps distantly related, facet. All the information gathered is potentially useful, but not necessarily essential for the solution of a practical problem. This is true for much entomological information. On the other hand, at least an equal amount of information is related directly to the short-term control or suppression of pest populations. A sustaining long-term approach has not been widely accepted as a realistic possibility; thus data have not been gathered to suit such an approach.

Classification and identification play an important primary role in the study of pathogens in insect populations, but there are so few workers involved in this area that an entomologist often can obtain only a very general name for a pathogenic or-

ganism. New micro-organisms associated with insects are being discovered at a relatively high rate, and with time we shall be able to provide more accurate identification. At present, a limited number of pathogens associated with a few pest species have been studied extensively enough to provide positive specific identifications. The actual naming of the micro-organism may not be as important as the understanding of its biology and ecology; therefore an entomologist or microbiologist should proceed with studies in these areas whether he has a name for the organism or not.

Simple numerical relationships (first-order relationships) should at least be examined. The incidence of the pathogen in the host species from one population to another (in space) and from one generation to another (in time) should be a primary consideration. This approach has already been used in the case of the European spruce sawfly, *Diprion hercyniae*, in North America where virus and parasite incidence data, collected regularly and systematically over a period of nearly 30 years, show that a nuclear-polyhedrosis virus exerts strong regulatory effects when host densities are high and that parasites are effective when host populations are relatively low (*Bird and Elgee 1957*; *Bird and Burk 1961*; *Neilson and Morris 1964*). The general sampling procedure used in the study of the European spruce sawfly can and should be used for the study of the numerical relationships of any micro-organism to its host.

Generally speaking, insects that die from disease and parasites fall to the ground, where they are difficult or nearly impossible to find, and soon decay. It is much easier and more accurate to collect a sample of living insects and place them in captivity for a period of time. During this time, with constant surveillance, all disease- and parasite-killed individuals can be detected, and the incidence of disease etc. for the time period can be estimated. From such incidence data, a series of samples in *time* and *space*, an accurate account of the interrelationships of the organisms can be constructed. This principle must be utilized more widely if we are to meet and solve pest problems on a sustaining scale, that is, without adversely affecting the general ecosystem for an extended time.

Incidence Differences

During the collection of such comprehensive incidence data, it is often discovered that a pathogen causes mortality only during certain stages in the life-cycle of the host (time), or that it has a high incidence in one population, but a low incidence in another (space) (*Harcourt 1966*). The reasons for these differences cannot necessarily be explained by the incidence data. For example, the relative susceptibility of individual hosts in a population may be highly variable, and certain stages may not be affected at all (*Stairs 1965*). Similarly, a population in one area may be composed of individuals that are generally more susceptible than those of a population occurring in another area (*Benz 1962*). To determine the ranges of host-susceptibility, experiments should be made under controlled conditions in the laboratory so that each individual can be observed more or less continuously. Once the general pattern and range of susceptibility are known, various field populations can be tested for specific differences by treating samples from these populations under controlled conditions in the laboratory.

An example to illustrate this procedure is the forest tent caterpillar, *Malacosoma disstria*-nuclear-polyhedrosis virus system. This pest insect species has been observed for nearly 100 years, and regular patterns of distribution and population fluctuations are evident. The species occurs over most of North America, but outbreak populations occur most frequently in the aspen stands that stretch across Canada and the northern United States. Many stands are stripped of early foliage for 5 to 8 years. During this time, parasites, predators, and diseases usually increase markedly and cause high mortality. In some stands, the major mortality factor may be parasites, while in others it may be virus. Often it appears that almost every larva in the population is infected with and killed by the virus. Following such decimation, the species may not be found in a stand for 8 or 10 years. This cycle of events is well documented and it suggests that the virus might be artificially disseminated for control of pest outbreaks (*Sippell 1962*).

In the early 1950's attempts were made to determine whether the virus could be applied to foliage to infect larvae feeding on

it, and thereby cause high mortality (*Bergold 1951*). Limited laboratory tests suggested that the larvae were relatively resistant to infection; thus only low mortality resulted. Therefore it was concluded that the virus would not be useful for artificial control of pest outbreaks. The questions of how the virus causes such massive mortality in natural populations were left unanswered. This presented a paradox. If it works in the field, why does it not work in the laboratory?

In the early 1960's some answers were obtained by a stepwise quantitative approach. Question one, what stages of the life cycle are susceptible to virus infection? The feeding larval stage, primarily. Question two, what is the relative susceptibility of young and old larvae? Many of the newly hatched larvae are susceptible to infection by a single virus unit, whereas many mature larvae are not susceptible to doses of a billion (10^9) virus units. Larval susceptibility decreases rapidly as the larvae grow older; thus the most effective time to disseminate the virus for population suppression is just as larvae hatch and begin to feed. Question three, what doses will cause high mortality? The food surface should be coated so that 100,000 (10^5) virus units are consumed by each young larva to ensure that 95 percent of the larvae will be killed (*Stairs 1965*). In actual field tests, concentrations of 10^7 polyhedra per ml. of water applied to thoroughly wet the foliage caused 92 percent larval mortality and prevented defoliation of the trees (*Stairs 1964*).

With answers to these three questions, we are able to predict the timing and quantity of virus that can be used for the successful suppression of pest populations, at least over small areas. The point of this discussion is that, when the problem was approached systematically by asking and answering the simplest and basic questions, a highly satisfactory result was obtained with a minimum of effort. This is, of course, a simplified example, but it illustrates that we do not necessarily need to obtain detailed information of a more complicated nature. It certainly illustrates that complicated theories can and do inhibit progress towards the utilization of pathogens for insect control.

Simple quantitative relationships should be understood before theories concerning viral latency are proposed. There is little doubt that this theory has been detrimental to the progress of research and the development of viruses for practical use. All sudden virus epizootics can be explained on simple numerical terms. Even in forest tent caterpillar populations an epizootic can be initiated by a single polyhedron or virus unit.

A first-instar larva may be susceptible to infection by a single polyhedra. Such an individual will die in 4 to 8 days and will contain approximately 10^7 polyhedra. This is a 10 million-fold increase in virus incidence in the host population. It is enough virus to cause lethal infections of 8,000 second- and third-instar larvae, provided the virus reaches the food surfaces that will be consumed by these larvae. The gregarious feeding habits of the larvae insure that the virus from a single diseased larva dying among the group will almost certainly be contacted by some of the healthy larvae. These larger larvae will, in turn, become diseased, and each may contain as much as 10^{10} polyhedra at death in the fourth or fifth instar. This is 1,000 times as much virus as is contained in a first-instar larva. It is not enough, however, to infect more than 100 fourth- and fifth-instar larvae. These older larvae are about 10^8 times more resistant to infection than are first-instar larvae, and much greater quantities of virus must be present on the foliage before high mortality results.

Many larvae that are only lightly infected at the time of metamorphosis complete development to the adult stage. These adults (both sexes) transmit virus to their progeny, and foci of infectious virus are assured in the next generation of hosts. Epizootics often result from these foci and also probably from virus that survives on the plant surface and in the soil layers.

Recent studies on the persistence of virus in the soil suggests that considerable quantities may accumulate during an epizootic and remain infectious over long periods of time. The nuclear-polyhedrosis virus of *Trichoplusia ni*, the cabbage looper, will survive several years in the upper layers of the soil (*Jaques*

1967 a,b), and there is every reason to believe that other viruses of this group will survive in the soil or duff layers at least as long. Virus in the soil may be transmitted to the food plant, and hence to the host larvae, by anything that moves or causes the movement of soil particles to plant surfaces. Rain, wind, insects, birds, etc., are obvious agents of dissemination. Since an epizootic can be initiated by a single infectious polyhedron, it is quite possible that epizootics can develop in host populations from virus that remains in the soil during inter-outbreak periods. It is obvious that any detailed study of virus-host relationships should include infectivity studies of the soil.

Many of the foregoing comments will apply to any pathogenic organism. The same set of questions must be asked and answered before we can utilize an organism with any degree of precision and prediction. The distribution of the pathogen and host in time and space must be measured, and pathogen-host numerical interactions will then become obvious. In all cases, a pathogenic species is capable of existing apart from its host, at least for brief periods of time; thus simple spatial and temporal relationships are of basic importance to the survival of both species. These should be the first relationships investigated, and adherence to this simple principle will always yield valuable information.

Toxins

Several groups of pathogens are known to produce toxins specific for insects. Perhaps the best known are those produced by the *Bacillus* group of bacteria. The familiar *Bacillus thuringiensis* or Bt preparations owe their activity against insects largely to the presence of highly specific toxic substances. Of course, these make good "insecticides." The fungi also produce many kinds of toxins, and among those pathogenic for insects, species in the genera *Beauveria* and *Aspergillus* have been investigated. Although none has been exploited commercially, these toxins are good potential sources for insecticides.

It is generally believed by insect pathologists that large quantities of infectious pathogens must be available if the utilization

of the pathogens is to be successful. Thus much effort has been placed on the mass-production of these organisms. Only those of the *Bacillus* group have been developed on a functional, commercial scale; that is, one can purchase various formulations off the shelf from a farm chemicals distributor (*Briggs 1963*). These formulations are approved by appropriate public health agencies in most countries.

Several insect viruses have been tested, but none are being produced and marketed by commercial companies in the United States, pending approval of the U.S. Food and Drug Administration. Several companies are producing relatively large quantities of specific viruses so that, when proper licenses are obtained, these organisms will be immediately available for use. For example, the corn earworm and cotton bollworm nuclear polyhedrosis viruses (*Heliothis spp.*) are available at present but are licensed only for experimental use (*Ignoffo 1968*). The regulatory agencies in other countries have not been as strict; so in Canada, for example, viruses of sawflies are utilized by Christmas tree growers and foresters without control or interference by any government agencies.

Large quantities of the sawfly viruses are produced by confining susceptible larvae in cages and feeding them food contaminated with virus (*Bird 1953*; *Smirnoff et al. 1964*). After they have fed for 5 to 10 days, larvae become infected and begin to die. When the first larvae die, all are removed from the food and confined so that additional dead individuals can be collected easily. In the case of *Neodiprion sertifer*, an infested plantation of young Christmas trees can be sprayed with virus and large numbers of diseased larvae can be collected in a short time (*Bird 1964*).

Virus-diseased larvae are suspended in water, allowed to putrefy for several weeks or months and purified by differential centrifugation. A force 100 to 800 times gravity will sediment the polyhedra. The purity of the preparation depends upon the number and accuracy of the centrifugation. Often crude suspensions of recently diseased larvae are used without any particular treatment, and these have proved very effective. In cases where highly active and very pure preparations are required, the mid-

guts of diseased, but not yet dead, larvae are dissected out, washed, and placed in suspension. Since the virus multiplies only in the midgut cells, a maximum of virus and a minimum of uninfected tissue are obtained. This is probably the most efficient way of obtaining quantities of highly purified virus. If need be, the lumen of the midgut can be flushed to remove food particles and associated organisms before the midgut tissues are placed in suspension. These suspensions are among the purest obtainable.

The same principles may be used in the multiplication and production of the viruses of Lepidoptera. For the purest of preparations, diseased tissues may be dissected from sick individuals, macerated, and suspended in water or saline. If high purity is not required, the sick larvae may be allowed to die. They must be collected quickly, however, before they become liquified and difficult to handle. At this stage they readily disintegrate upon suspension in water, thus the virus is efficiently dispersed in the suspending medium. Often other microorganisms, especially bacteria, are present in such preparations, and it may be desirable to remove these, although they are not normally pathogenic. This may be done by using differential or zonal centrifugation techniques. Centrifuge techniques have much improved, and very pure, large quantity preparations can be obtained.

Host Larvae

Another problem in the production of large quantities of virus is the availability of a large number of host larvae. It is most convenient and least expensive to collect larvae from areas supporting high populations, bring them to the laboratory, infect them, and recover the virus (*Stairs 1964*). The recent development of artificial food media, however, has made possible the large-scale rearing of several pest species on a year-round basis in the laboratory (*Ignoffo 1968*). More progress will be made in this area in the immediate future, but even now several successful rearing programs are under way.

The infection of host larvae with virus is usually accomplished by contaminating the plant or food surface upon which

larvae are feeding. At high dosage levels a high proportion will usually succumb to virus disease. Occasionally the full-grown larvae are highly resistant to oral infection (*Stairs 1965*). For example, last-instar *M. disstria* larvae are very resistant; thus infection by feeding is very inefficient, so virus multiplication using this approach is not successful. To overcome this problem, virus particles, freed from polyhedra by pH treatment, were injected directly into the hemocoele. In this way, relatively low dosages caused very high disease mortality, and an extremely efficient method of virus multiplication was developed. Mature, fully fed larvae were collected from field populations, brought to the laboratory, injected with virus, and observed daily. Dead and dying individuals were removed and suspended in water. Often these suspensions were used immediately for dissemination into healthy host populations with good results. It was also found that storage in water at 4°C. in the dark for several months did not cause appreciable loss of viral activity.

The large-scale development of insect cell culture offers another method for the production of viruses and other obligate pathogens (*Grace 1962, 1966*; *Mitsuhashi 1966*; *Vaughn 1968*). However, many problems are associated with these artificial systems that must be solved before this approach can be employed successfully. For example, many cell lines are difficult to infect with viruses (*Vaughn and Faulkner 1963*).

Perhaps one of the most important factors in the successful utilization of a pathogen in the suppression of a pest population is insuring that enough of the pathogenic organisms reach the individual insects to cause lethal or debilitative infection. Certainly if the food plant (or other substrate) is thoroughly covered with a suspension (or dust cloud) of viable organisms, the chances of occurrence of infections are maximal. Water suspensions have proved to be satisfactory for small-scale tests, as have certain dust preparations (*Bird 1953*; *Thompson and Steinhaus 1950*). Emulsions have also been found to be effective (*Clark and Reiner 1956*; *Smirnoff et al. 1962*). Any sprayer that does not generate excessive heat may be used to disseminate pathogenic microorganisms. Aerosol space sprays and mist-blowers may be the most effective means of disseminating in-

sect pathogens. Much more quantitative investigation in this area must be done before maximum efficiency of dissemination is realized.

The integrated approach to pest control requires the manipulation of more than one factor of the pest's environment to cause a reduction in population and damage. Chemical control is based on the introduction of a poison into the insect's environment to cause mortality and population reduction. Similarly, parasites and predators have been introduced, usually one species at a time, to effect reductions in pest population levels. Very few attempts have been made to use a combination of chemicals, parasites, predators, and pathogens for the regulation of numbers of a pest species.

This approach is relatively complicated; and it requires, at least, that incidence data in space and time be obtained to determine the impact of each factor individually and collectively on the pest population levels. With these data in hand, relatively accurate predictions of population levels can be made, and the best manipulative procedures can be selected. In many cases, the artificial numerical increase of pathogens may be easiest and most effective over large areas. Local, small infested areas (fields or forest stands) may require careful treatment during a pest generation with a chemical to prevent excessive damage and great financial loss to an individual without causing undue disruption of the ecology over large areas. Similarly, local areas may be inundated with a pathogen, parasite, or predator. The result, however, may not be rapid enough to prevent damage and some financial loss. Modifications of these approaches are potentially useful in the management of many pest organisms, but they will be especially useful in the effective regulation of some of our major insect pests of forests.

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PARASITES

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INTEGRATED CONTROL signifies the selection and use of various methods of applied control to harmonize with the natural control factors already operating. It cannot be applied until the roles and relative importance of these natural control factors are known. The prerequisites to its use are a knowledge of both basic ecological principles and the ecological features that are specific to each target species. The goal is to achieve the minimum degree of damage to the product that is consistent with both minimum damage to the environment due to side effects of control measures and maximum long-term economy. These side effects, primarily due to insecticides, are now well known: (1) development of resistance, (2) resurgence of treated populations, (3) outbreaks of secondary pests, (4) contamination of the environment by persistent poisons, and (5) destruction of beneficial species.

Objectives of Biological Control Programs

In the past, the degree to which a biological-control operation has been considered successful has been judged on the extent to which the introduced agents have provided the ultimate in control—the permanent maintenance of a pest's abundance below the level of economic injury. For example, DeBach (*1964*) differentiates between outstanding success, substantial success, and partial success. The assessment of a particular case is made on the basis of: (1) the proportion of the total range of the pest in which control is achieved, (2) the degree to which the duration or severity of outbreaks is reduced or the duration of the

intervals between outbreaks is increased; (3) whether supplementary control methods must be used, and (4) whether a pest is of great or slight economic importance.

It has been suggested, for example by Prebble (*1960*), that with certain types of pests where only very high densities cause appreciable damage, a program might be deemed fully successful if the degree of economic injury is significantly reduced even though less severe and less prolonged outbreaks still occur.

The biological-control program against the gypsy moth can be cited as an example where the evaluation of degree of success would depend on what the original objective of the program was considered to be. DeBach (*1964*) rated it as a "partial success" even though Clausen (*1956*) said that the end result in America was that outbreaks were reduced to a level "comparable in range and severity" to those occurring in Europe. If this degree of control had been set originally as a realistic objective, then the final rating might have been a substantial or even an outstanding success. In this program the effectiveness of the introduced agents has undoubtedly been inhibited by the continuing and widespread use of insecticides against the pest.

Although biological-control specialists have long recognized the importance of partial control, some of the early spectacular and complete successes have encouraged the setting of impossibly high standards for judging the usefulness of biological-control attempts. Such standards discourage attempts aimed toward partial control, which could reduce the frequency, severity, or duration of damage. Prebble (*1960*) criticized this all-or-none attitude toward control operations as being incompatible with our increasing knowledge of population dynamics and forest ecosystems; but the attitude still persists.

Philosophy Underlying Biological Control

Biological-control workers have stressed the importance of governing factors in the total complex that restricts population increase. Governing factors are defined as those that are affected by changes in population density and, as a result, modify their influence so as to oppose population change (*Nicholson 1954*). However, many factors to which the above definition of

governing can be applied, are restricted in their ability to influence population change. These factors may have a limited ability to respond to large increases in density and operate only in endemic populations. Certain parasites of spruce budworm (*Miller 1963*) and elaterid predators of the pine looper (*Turnock 1969*) are examples. Other factors such as diseases may operate only at high densities.

The relative importance of parasites that are effective at low host densities versus those capable of reducing outbreak populations is one that cannot be answered on the basis of available information on population dynamics. The most effective parasite species would be capable of operating effectively both at low host densities and under outbreak conditions. Certainly some parasites that are capable of terminating an outbreak are also effective at low densities: *Cyzenis albicans* and *Agropyron flaveolatum* on the winter moth in Nova Scotia (*Embree 1965*); *Agathis pumila* and *Chrysocharis laricinellae* on the larch casebearer in eastern-central North America; *Olesicampe benefactor* on low larch sawfly populations in alpine Europe and outbreak populations in Manitoba. On the other hand, the collapse of the original European spruce sawfly outbreak in North America was caused by an introduced virus, while subsequent outbreaks have been controlled by the combined influence of the virus and two parasite species, or, in some cases, either virus or parasites acting alone. The parasites are particularly effective at very low host densities and are sensitive to minor fluctuations at these levels (*Neilson et al., in press*).

We suggest that, wherever a particular biotic agent has the capability of maintaining population levels permanently within given limits of abundance that are non-damaging, the qualifying word "effective" be used to describe it. Such agents are effective as long as the non-governing mortality factors show no marked deviations from their long-term average influence.

It seems probable there may be situations in which a complex of governing factors, none of which by itself is an "effective governing agent," act together in such a way as to be effective. The possibility of "stacking" a number of partially governing agents to attain effective control requires more study. A basic

cleavage of opinion exists as to whether or not a single introduction of the best possible parasite species is preferable to multiple introductions. Though while the introduction of competing species may be detrimental to the more efficient of the two, i.e., the case of *Eulimneria rufifemur* interfering with *Orgilus obscurator* attacking the European pine shoot moth (*Pschorn-Walcher et al. 1969, Syme in press*), such examples cannot be automatically extended to reach the conclusion that a single parasite species will be more effective than several species.

Non-governing factors such as weather may be necessary components of processes that are density-dependent in action. For example, when the average degree of protection afforded by living places decreases as population density increases, percentage mortality due to adverse weather also increases. Similarly, crowding phenomena may render individuals more susceptible to adverse weather by changing their behavioral and/or physiological characteristics.

Insecticidal applications usually correspond in their effect to the catastrophic mortalities that occur when weather conditions are severe. Since they are normally applied only at very high densities of the pest, they are density-dependent to a degree. Their application, however, may elicit the sort of homeostatic mechanisms that force the pest to remain at high densities most of the time (*National Academy of Sciences 1969*). The spruce budworm outbreak in south-central New Brunswick apparently illustrates this situation: since 1960, an average of over 1,600,000 acres has been sprayed annually to minimize tree mortality. Although this objective has been attained, the outbreak continues and surveys indicate that 10 million acres will be defoliated in 1970 (70 percent of them will have moderate to severe defoliation) and plans are under way to spray about 3 million acres.

It should be possible to use insecticides in a density-governing way by interposing man as the controlling component to create a feedback loop. In such a case the application of insecticides would be varied in time, space, and intensity to stabilize population levels rather than to produce high mortalities. Man

may also be able to achieve such results by regulating microclimates; for example, the humidity in tree nurseries or plantings could be modified to vary the intensity of mortality due to disease. Other control methods that could be utilized in a governing way through human intervention are: the use of antifeedants, repellents, pheromones, chemosterilants, radiation sterilization, electromagnetic energy, and behavioral or genetic manipulation.

It has been implied above that the reason most pest species are pests is because there are no effective governing processes acting against them. Even with pest species, however, certain governing processes eventually come into play if density continues to increase, namely those connected with food shortage, or reduced fecundity or viability. Below such density levels it is likely that non-governing processes connected with weather, food quality, etc. are major determinants of annual changes in population level.

Among the reactive factors it is parasites, invertebrate predators, and diseases that are considered to have a special potential for governing populations. Although their functional responses and "behavioral numerical responses" (*sensu Buckner 1966*) may be of considerable importance, particularly at lower levels of host density, their most important characteristic is that their "breeding numerical response" (*sensu Buckner 1966*) is potentially limited only by host density and is not restricted by factors such as territorial behavior.

The breeding numerical response of a particular species is probably at least partly dependent on its functional response (i.e., if there is an increase in the number of hosts attacked per parasite with an increase in host density, this results in an increase in the ratio of adult parasites to adult hosts in the next generation). In order for the agent to exert a governing action, the total response during one or more generations to an increase in host populations must result in a sufficiently large increase in mortality to cause a reversal of the population trend. The behavioral numerical response of avian predators to concentrations of insect prey certainly increases prey mortality (*Buckner and Turnock 1965; Mattson et al. 1968*), but its effec-

tiveness as a governing factor is not well documented.

In the control of the Klamath weed by *Chrysolina quadrigemina* in California and the prickly pear cactus by *Cactoblastus cactorum*, the phenomenon of local annihilation of both host and agent has occurred. This has been followed by re-invasion; first by the host and later, sometimes after an interval of sufficient duration to allow the host to build up appreciably, by the agent. Huffaker and Messenger (*1964*) state that following re-invasion of the Klamath weed, a great variety of forces (rainfall, temperature, fire, etc.) may devastate or destroy these stands in the absence of the beetle. A population-dynamics study in such stands during this period would show that physical factors would be of major importance in determining annual changes in population levels. They state, however, that the beetle still holds the key role since whenever stand densities become threateningly high the beetle invariably arrives by dispersal from residual populations elsewhere and drastically reduces or annihilates these populations. The true role of the beetle could be determined only by a long-term population-dynamics study.

It is not known how important local annihilation and resulting fragmentation of host populations is when insect pests are controlled by biotic agents, but it is obviously worthy of considerable study. Wolcott (*1958*) cites two examples where biological control of pests in Puerto Rico was too successful, resulting in the disappearance of the agents from the island and the later reappearance of the pests, but not the agents. In continental areas the phenomenon may be of relatively common occurrence, particularly with hosts against which biological control has been successful; but if the local annihilation occurs over a comparatively small area and is of relatively short duration, it would be difficult to detect. Andrewartha and Birch (*1954*) believe it is going on around us all the time, although due to underpopulation phenomena rather than to excessive kill by biotic agents, whereas Varley and Gradwell (*1970*) believe it is not common in the field.

At the borders of distribution of some species, environmental pressure may be so severe that only temporary existence is pos-

sible, and it is usually only in the more optimal areas that a pest species periodically increases to excessive numbers. In the intermediate areas the species may be a relatively permanent occupant, but its numbers rarely rise to injurious levels. In these areas it probably becomes extinct periodically, and populations are re-established by immigration from the optimum zone. If the only effective governing processes in the optimum zone are those connected with depletion of the food supply, we should not expect to find other governing processes in the intermediate areas where, because of the lower densities of host, there is no competition for food. A possible example of such a species is *Bupalus piniarius*, which is a serious pest in Germany, England, etc., where it is limited mainly by food depletion. A thorough population-dynamics study of low-density populations in Holland (*Klomp 1966*) failed to reveal the presence of an effective governing homeostatic mechanism.

It has long been postulated (*Nicholson and Bailey 1935*) that a delay or lag in the response of a parasite or predator to an increase in host density gives rise to coupled oscillations of host and agent that increase in amplitude with time and are inevitably self-destructive. Varley and Gradwell (*1970*) state that only specific and synchronized enemies act in this way. This would suggest that such specific enemies would not be effective biological control agents. Support for this view is given by the conclusion of Liu Chung-lo (*1962*) whose analysis of 30 successful attempts indicated that moderate polyphagy will better ensure success than monophagy. On the other hand, Doutt and DeBach (*1964*) conclude that most successes in biological control have resulted from the introduction of rather host-specific entomophagous species having good synchronization.

Klomp (*1966*) states that oscillations of increasing amplitude are never observed under natural conditions because they would lead to extinction. However, such oscillations might occur in nature under unusual circumstances such as the introduction of a specific, well-synchronized parasite. This may have occurred in Puerto Rico, where the extinction of two entomophagous species was observed. The lack of observations of this phenomenon may be related to its ephemeral nature: either the system is

stabilized or extinction occurs rapidly.

Coupled oscillations of increasing amplitude can be stabilized into coupled oscillations of approximately constant amplitude by damping mechanisms. As a generality, a damping mechanism can be any interference component that reduces the efficiency of enemies as prey density increases. Varley and Gradwell (*1970*) concluded from a study of models that it is impossible to mimic the coexistence of two specific parasites unless each is provided with its own density-dependent mortality. Huffaker and Kennett (*1969*) present data indicating that the effective area of discovery (searching capacity) of the ichneumonid *Venturia canescens* decreases as host density increases, and this would tend to dampen oscillations because the parasite is acting as its own density dependent factor.

Do the results of population-dynamics studies lend support to the above views? Studies on defoliators that occasionally reach very damaging densities, such as the spruce budworm (*Morris 1963*), the lodgepole needle miner (*Stark 1959*), and the larch sawfly (*Ives et al. 1968*), indicate that the determination of density levels below those causing food shortage is usually due to climatic causes or non-governing biotic agents. There are certain biotic agents that seem to become abundant only after very high densities are reached; and although these may play an important role in decreasing the duration of outbreaks, they are not effective in terms of governing—i.e., preventing the excessive increases in host density in the first place.

Some species that have been studied intensively have been shown to have their densities at all levels determined mainly by parasites. One of these is the black-headed budworm in the Maritimes (*Morris 1959*; *Miller 1966*) which, in this region, occasionally reaches high densities for short periods. Miller concluded that population release was associated with years of low parasitism and favorable weather, while population decline was associated with late larval parasitism. This defoliator has caused mortality of western hemlock on the West Coast, and a population analysis in this area might show a basic difference in the population-level determinants as compared to the Maritimes. Varley and Gradwell (*1970*) caution that in Morris's analysis,

parasitism is causally responsible for rather less than half of the population change, even though estimations of parasitism in year N allow a reasonable prediction of population density in year N+1. This is because the residual mortality varies in a way similar to variations in larval parasitism, and these authors believe that the unstudied aspects such as parasites or predators acting in the egg or pupal stages contain a major cause of host density fluctuations. They believe an identical situation occurs in the case of the grey larch moth (*Zeiraphera diniana Gn*). Concerning this latter species, however, Auer (*1969*) concluded, from an analysis using a five-factor model, that, within the optimal area, "The biological and density-dependent actions are much more efficient than the abiotical actions." Preliminary results of a study of the fall webworm (*Morris 1969*) indicate that American populations are maintained at a low level mainly by the effects of heat accumulation on survival. However, he suggests that simulation studies using a biologically meaningful model, now in preparation, will be necessary to determine the role of density dependence in the webworm's system of regulation.

The results of these studies give conflicting answers to the question of whether effective governing factors maintain the low densities of non-pests. Many studies have documented the absence of effective governing factors during epidemics of pestiferous species which, at such times, can be aptly described as out of control. There have been too few attempts to identify the presence of such factors in species that have never been pestiferous. Comparative studies of population regulation of pests under both endemic and epidemic conditions are necessary for the development of rational pest management.

Classification of Pestiferous Species

The "classical" approach to biological control was initially developed when it was realized that exotic pests commonly lacked the natural agents that prevented their depredations in their place of origin. Unfortunately, however, the idea that biological control consisted solely of the introduction of enemies from foreign lands has tended to dominate discussions of the

potential of biological control (*e.g., Simmond's 1956 critique of Taylor 1955*) to the detriment of consideration of alternate approaches and emphasis on the need to fit the approach to the characteristics of the target species.

There are different types of pests that vary in their suspectibility to the classical approach, and in this paper we recognize four categories of pest insects that differ in their origin, the mechanisms that determine their population levels, or the relative densities at which damage occurs.

1. *Exotic pests:* species originating from other regions, which lack the effective governing mechanisms that are present in their native habitat.

2. *Anthropogenic pests:* species whose populations reach damaging levels due to changes made in the environment by man's activities.

3. *Opportunistic pests:* species with a "wide-amplitude" type of population behavior (*Watt 1968*), which periodically reach very high densities in response to favorable environmental conditions.

4. *Low-density pests:* species that occur at low densities, apparently due to the action of effective governing mechanisms, but nevertheless cause economic damage.

Exotic pests have traditionally been considered the most promising targets for biological-control operations because, in their native habitat, they occur at non-economic densities, presumably due to effective governing mechanisms. Living biotic agents are important components of governing mechanisms, and these agents often can be transported and established in the invaded region.

Anthropogenic pests resemble exotic pests in that they are effectively governed in some areas, but differ in that they are not effectively governed in habitats that have been greatly modified by human activity. Since effective biotic agents usually exist in adjacent undisturbed areas, these modifications appear to have created an environment that limits the effectiveness of these agents. Biological control through colonization is therefore un-

likely to be successful unless (1) the environment is changed to ameliorate the limiting factors or (2) biotic agents adapted to the modified environment are discovered or developed.

Opportunistic pests are characterized by extraordinarily wide-amplitude population fluctuations wherever conditions of food and weather are favorable. Their great reproductive potential and great powers of dispersal resemble those of the opportunistic species described by Cole (*1966*): "plants and animals that are normally inconspicuous but that quickly invade and occupy a temporary habitat." These pests may be attacked by a large complex of biotic agents, but are regarded as being largely under the influence of density-independent rather than density-dependent factors (*Watt 1968*).

The lack of sources of new biotic agents attacking pests of this type has discouraged the biological control approach, and the few attempts made have failed (i.e., the spruce budworm; *Miller and Angus, in press*). Although these species are frequently abundant over wide areas in their native lands, it is remarkable that few of them have become pests in other continents. This apparent inability to colonize new areas may be related to the importance of density-independent factors in their life systems. The same non-governing factors that determine generation survival in the native land are likely to be present and of similar importance in the new environment. The chance of such a species becoming established in a new region might therefore only be high during the relatively brief periods when these factors are favourable. On the other hand, species whose fluctuations are determined by biotic governing factors, except competition for food, escape these governing influences in a new environment and commonly find combinations of density-independent factors that are suitable for both establishment and rapid increase.

Thus a species exhibiting low-amplitude population fluctuations in its native home would probably be characterized by wide-amplitude fluctuations in a new environment, possibly exceeding those characteristic of native opportunistic pests. Such species in a new environment may continue to increase until the food supply is almost totally destroyed, thus leading to their

own extinction in localized areas and marked instability of the ecosystem of which they form a part.

Low-density pests present a difficult problem for biological control. They do not exhibit wide-amplitude population fluctuations and are usually considered to be well governed. Since effective density-dependent agents are already present, there is not much scope for classical biological-control approaches. This category includes many of the species called "direct pests" by Turnbull and Chant (*1961*) but excludes those direct pests that attain high densities. Although classification on the basis of direct or indirect damage is useful for emphasizing the degree of population reduction necessary for economic control, classification on the basis of the population dynamics of the pest gives a more realistic evaluation of the best strategy for an integrated control program. For example, *Adelges piceae* is a species that is classified as a "direct pest" by Turnbull and Chant (*1961*). We would classify it as typically anthropogenic in Europe, where it is endemic on the older trees of the common silver fir *Abies alba* in mature stands but often a pest in the mixed age plantings that have been made outside the natural range (*Pschorn-Walcher 1964*), and as typically exotic in America.

The development of integrated control strategies must be based on both the population characteristics of the pest and the various types of control operation that are available. Past experience, theory, and investigation of specific situations should dictate the most promising integrated control approach. A large proportion of past biological-control programs have utilized parasites; and this experience, plus the theory developed from population-dynamics studies, provides a basis for utilizing parasites in integrated control programs.

Analysis of Programs Against Forest Insects

The history of biological-control attempts against forest insects in North America has been reviewed by Dowden (*1962*) and McGugan and Coppel (*1962*). They list 44 target species for programs in which parasites were used; and we added a 45th species, the holly leaf miner, following Turnbull and Chant

(*1961*). Since the period covered by these reviews, a few new programs involving parasites have been initiated: against the larch sawfly, the European pine shoot moth, the European pine sawfly, and the winter moth in Canada; and against the European elm bark beetle, the larch casebearer, and the western spruce budworm in the U.S.A.

The record of parasite releases against forest pests is rather blurred and confused in places. In attempting to evaluate this record, we have been forced to make decisions regarding the various programs on the basis of incomplete data. The results may be biased, but, if we are to advocate the use of parasites in integrated control programs, we must be prepared to give some estimate of the chances of success.

On the basis of published information, each target species was classified as to pest type (exotic, anthropogenic, opportunistic, low-density) and whether it was a "prime" or "alternative" target for parasite releases: prime targets are known to be hosts of the parasite species released against them; alternative targets are those against which parasites from related host species were released on the basis of a reasonable chance of success or merely to dispose of surplus material. In this empirical evaluation it was necessary to exclude a large number of the programs listed because: release and recovery data were inadequate; the parasite was probably already present; only a single release of the parasite was made; the parasite was introduced to Canada from a subtropical source; the parasites released were obtained from host species distantly related and ecologically dissimilar from the target species.

Most of the 21 programs that were considered amenable to analysis, and most of the successful programs, were against exotic pests (table 1). Only three attempts were made against anthropogenic and two against opportunistic pests. Among these five, the single successful biological control attempt was against an anthropogenic pest, the pine tip moth, and in this case the pest situation had many resemblances to that of an exotic pest: serious damage to pine plantations was being caused by *Rhyacionia frustrana bushnelli* in Nebraska where effective parasites were absent; while *R. frustrana frustrana* in Virginia was effec-

Table 1—Target Species for Major Biological Control Programs Using Parasites Against Forest Insects in North America

Species	Origin	Type[1]	Results[2]
HOMOPTERA			
Lecanium tiliae L.—lecanium scale	Exotic	Prime	C
Gossyparia spuria (Mod.)—European elm scale	"	"	S
COLEOPTERA			
Galerucella xanthomelaena (Schr.)—elm leaf beetle	"	"	C
DIPTERA			
Phytomyza ilicis (Curt.)—Holly leaf miner	"	"	C
LEPIDOPTERA			
Choristoneura fumiferana (Clem.)—spruce budworm	Native	"	U
Cnidocampa flavescens (Wlkr.)—oriental moth	Exotic	"	C
Coleophora laricella (Hbn.)—larch casebearer	"	"	S
Hemerocampa leucostigma (J. E. Smith)—white-marked tussock moth	Native	Alternative	U
Lambdina fiscellaria (Guen.)—eastern hemlock looper	"	Prime	U
Operophthera brumata (L.)—winter moth	Exotic	"	S
Porthetria dispar (L.)—gypsy moth	"	"	C
Nygmia phaerrhoea (Donov.)—brown-tail moth	"	"	C
Rhyacionia frustrana bushnelli (Busck)—pine tip moth	Native	"	S
Rhyacionia buoliana (Schiff.)—European pine shoot moth	Exotic	Prime	U
Stilpnotia salicis (L.)—satin moth	"	"	C
HYMENOPTERA			
Diprion hercyniae (Htg.)—European spruce sawfly	"	"	S
Diprion similis (Htg.)—introduced pine sawfly	"	"	S
Heterarthrus nemoratus (Fall.)—birch leaf-mining sawfly	"	"	C

Neodiprion lecontei (Fitch)—red-headed pine sawfly	Native	Alternative	U
Neodiprion sertifer (Geoff.)—European pine sawfly	Exotic	Prime	U
Pristiphora erichsonii (Htg.)—larch sawfly	" [3]	"	C

[1]See text for definitions.
[2]U = Unsuccessful, C = Contributive, S = Successful—See text for definitions.
[3]Origin disputed but here listed as "Exotic" because of its poor complex of parasites in North America (*Pschorn-Walcher 1963*).

tively controlled by parasites (*Dowden 1962*). The distribution of the two subspecies was disjunct, and thus this example cannot be used to predict the results of parasite releases against anthropogenic pests.

Consideration of the results of parasite releases against native (anthropogenic plus opportunistic) and exotic pests suggests that prospects for manipulating pest populations with pest releases are quite good (table 2). At least one new parasite was established on all the exotic species and on 40 percent of the native target species. The lesser success of releases against native target species may be taken to indicate that these pests are less suitable to the establishment of new parasites, but the record also suggests that the effort applied to these programs has been less than for introduced pests: the average number of parasite species released per native pest is 7.8; per exotic pest it is 9.4.

The results indicate that the prospect for quantitatively increasing the parasite complex is high for exotic pests and reasonably good for native pests. The fortuitous establishment of parasites released against the gypsy and browntail moths, the European spruce sawfly, and the European pine sawfly also shows that the parasite complex of native species can be increased by introductions.

The rate of successful establishment in relation to the total number of parasite species released was approximately one-third (table 2). This is undoubtedly a gross underestimate of the probability that an introduced species can be established, because in many programs difficulties with handling, synchroniza-

Table 2.—Results of Biological Control Programs Using Parasites Against Forest Insects in North America

Origin of target species	Type of program[1]	Number of species		Establishment (%)—		Control[1] (% of target species)			Excluded species
		Target	Parasites released	on target spp.[2]	of parasite spp.[3]	C	S	C + S	
		No.	*No.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*No.*
Native	Prime	3	28	33	4	0	33	33	2
	Alternative	2	11	50	18	0	0	0	17
Exotic	Prime	16	151	100	37	56	31	88	2
	Alternative	0							3
All species	—	21	190	90	32	43	29	71	24

[1]See text for definitions.
[2]Target species on which at least one new parasite was established/total target species.
[3]Number of parasite species established/total number of species released.

tion, and small numbers of parasites available, mitigated against success. In our own experience, the failure of four of the six species of parasites released against the larch sawfly since 1961 can be attributed mainly to our lack of knowledge of conditions necessary to ensure mating and maintain vigor of parasite adults between emergence and release (*Turnock and Muldrew, in press*).

Evaluation of the effect of the introduction of a parasite on the target species should be based not only on its contribution to a reduction in pest population levels, but also to the reduction in damage to trees. Unfortunately, such information is rarely collected, and for many programs even crude data on the level of parasitism in the population is available for only a few years following the release. We therefore evaluate the biological-control programs on the basis of three categories:

1. *Successful:* populations and damage reduced to acceptable levels.

2. *Contributive:* introduced parasites causing appreciable mortality and believed to be contributing to the reduction of the intensity, duration, or frequency of outbreaks of the target species.

3. *Unsuccessful:* released parasites either not recovered, or occurring sporadically or at very low numbers.

Successful control was attained against 31 percent of the exotic and 33 percent of the native pests that were prime targets for parasite introduction. Contributive control was attained against 56 percent of the exotics but none of the native pests. The latter group comprises too small a number of species to allow the conclusion that parasite introductions are unlikely to contribute to the control of native pests.

Evaluation of Past Programs

Parasite release has been shown to have had some controlling effect on pest populations in a remarkably high proportion of the attempts, even though cases have been included where the

knowledge and resources applied to the program were minimal. The failure to adequately support biological-control programs can in part be attributed to the prevalence of too casual an attitude to the problems of parasite establishment. Although we eliminated from consideration many ill-conceived or poorly executed programs, the remainder still includes cases where parasites were released in poor condition, in poor synchronization with the preferred host stage, unmated, in inadequate numbers, or in suboptimal environments.

The problems of past programs can be attributed basically to a lack of proper standards in scientific procedure. Too often, little attention has been paid to researching the problems, to selecting appropriate biotic agents, to ensuring proper care of these agents before release, to selecting optimum release areas, and to assessing the host-density determinants before and after the initiation of the program. Reasons for this have been that many programs were conducted by forest entomologists lacking an adequate background in population dynamics and biological control and that financial support has been inadequate. Past expenditures on biological control have been small in relation to both the benefits achieved and the expenditures made on chemical control. The favorable cost-benefit ratio of biological control would be even more impressive if the costs due to undesirable side-effects of chemical control and possible future detoxification of polluted environments could be included. At present there is too little appreciation of the relatively low cost and lasting benefits of biological control. Since there is slight incentive for industry to develop biological control, public bodies must accept the responsibility for encouraging and supporting this type of program.

Recommendations for Parasite Use in Integrated Control

Integrated control for forest pests is applied population dynamics (*Balch 1964*). Continued maintenance of pest numbers below the economic threshold for damage must be based on knowledge of pest ecology and damage thresholds. In selecting

control methods for use in integrated programs, an attempt should be made to forecast the effects of specific actions on other mortality factors and short- and long-term population trends. In the absence of good models for predicting population trends, integrated control planning should initially concentrate on the evaluation of existing natural control. In analyses of the target species, the efficiency of natural and applied control factors and their inter-actions must be examined for different stages of the insect and for different ecological situations in which the pest occurs.

The concept of "guilds" of biological agents attacking a pest appears to be a very useful tool in planning integrated control. Root (*1967*) defines a guild as "a group of species that exploit the same class of environmental resources in the same way. This term groups together species, without regard to taxonomic position, that overlap significantly in their niche requirements." This can be considered as an expansion of the concept of "parasitological niches" defined by Zwolfer (*1961*) in the following way: ". . . holometabolic insects (possess) several biologically and ecologically differentiated stages, which are attacked by a number of different types of parasites. Host species such as these offer to entomophagous insects a system of diversified opportunities for oviposition and larval development, providing what, in analogy with the ecological niches of the habitat, may be considered as a complex of parasitological niches."

Although this concept is useful in investigating the parasite complex of pest species to reveal niches where the parasite complex is deficient in species or in effectiveness, the "guild" concept has a wider application. The target species can be considered as offering a complex of niches, which are exploited, to a greater or lesser degree, by the various guilds of biological agents. These guilds may attack different life stages of the pest, or individuals that occur in particular parts of trees, stand types, or site conditions. For example, for certain pests it may be sufficient to determine that the guild of larval parasites, predators, and diseases is lacking in species and effectiveness, while for other species the larval guild may be efficient in some stands and climatic zones but not in others. Thus in west-

ern larch stands the larch sawfly larval parasite guild appears reasonably effective (*Molnar et al. 1966*) while the same guild is ineffective in continental stands of tamarack, apparently because the "resistant" strain of larch sawfly is present (*Muldrew 1953*), as well as in tamarack stands of Newfoundland, possibly because of unfavorable climatic conditions. The approaches to integrated control in these three situations would be quite different.

Utilization of parasites in control operations can involve various methods of releasing parasites, of enhancing parasite efficiency by manipulating other aspects of the environment, and of using parasites to improve other mortality factors. Most parasite releases against forest insects have been of the *colonization* type: a relatively small colony of a new parasite species is established in a region where it is expected to become a permanent part of the natural control complex.

Inoculative releases are periodic releases in which control is dependent upon progeny being produced for more than one generation following colonization. They are usually made to establish an enemy in areas from which it is temporarily absent due to adverse environmental conditions, and they have been used against agricultural and horticultural pests (*DeBach and Hagen 1964*), but not in forestry. Integrated control of pests of trees at the periphery of the range of effective parasite species might well involve such inoculative releases. In addition, inoculative releases early in the development of an outbreak could be used to speed parasite response to pest population increases.

Inundative releases are also periodic, but are made to control a pest by the actions of the natural enemies released, not by their progeny. Their potential has not received much attention in forest entomology, but they might be used to advantage in relatively small areas where chemical insecticides are undesirable but which are not suitable for the application of pathogenic insecticides: e.g., where the terrain, tree size, or stand density are unsuitable for the spray equipment. The application of this technique depends on the availability of large numbers of parasites at low cost. The egg parasite *Trichogramma* has

been used in this way against agricultural pests, and tests against the spruce budworm in western North America are now planned. Larval and cocoon parasites offer some promise for use in inundative releases in incipient outbreaks where damage caused by the target generation of the pest can be tolerated.

The enhancement of parasite effectiveness through environmental manipulation to eliminate or ameliorate conditions detrimental to the maximum expression of control potential of parasite species must play an important part in pest management. As a first step, the effects of poor timing or unnecessarily high kills associated with insecticidal control must be minimized. Integrated control will not progress far until the use of applications of chemical and biological insecticides at dosages causing nearly 100 percent mortality is confined to situations where such applications are essential: i.e., small areas of high-value crop with low damage thresholds and situations where eradication is possible. Insecticidal applications should be aimed at achieving the minimum mortality compatible with crop protection.

Information on the critical factors influencing the abundance of parasites and their ability to control their hosts is sadly lacking. The widely accepted idea that host abundance is usually the major factor controlling parasite abundance appears logically untenable in the light of studies of phytophagous species. Since many of the latter are prevented by other factors from fully exploiting their food source, we should expect a similar situation to exist for many parasite species. Studies of the population dynamics of parasitic species are badly needed to elucidate their controlling mechanisms.

The presence of special habitats, other than those occupied by their host, may be necessary for the survival of some parasite species. Flowering plants may be used as feeding sites for some species; e.g. two parasites of the European pine shoot moth leave the pines to dwell among the flowers of Umbelliferae (*Thorpe and Caudle 1938*), and the preoviposition period of female *Eucarcelia rutilla* is spent in oak rather than pine woods inhabited by its host (*Herrebout 1967*). The absence of

alternate hosts may limit the efficiency of some polyphagous parasites, particularly where a univoltine host is attacked by a bivoltine parasite. Increased parasite effectiveness might be attained by providing suitable alternate hosts, perhaps by encouraging plant species on which they feed. Other possibly limiting aspects of the environment which might be manipulated by management techniques are: shelter for overwintering parasite adults; protection from biotic enemies (e.g., ants), and improvement of the physical environment through the encouragement of specific plant growth for shelter.

Another opportunity for improving the efficiency of parasites lies in the selection of superior genetic strains for release against the target pest. This approach has been used in Manitoba against the larch sawfly. Muldrew (*1953*) showed that the larch sawfly in Manitoba was capable of encapsulating and killing the eggs of *Mesoleius tenthredinis*. This resistant strain has since spread until it now occurs from northeastern British Columbia to Nova Scotia. Experimental testing of *M. tenthredinis* from Europe and Japan revealed that the *M. tenthredinis* from Bavaria was capable of overcoming the encapsulation reaction of "resistant" larch sawflies and that this ability was inherited by the progeny of Canadian and Bavarian crosses. In 1963 and 1964, releases of Bavarian *M. tenthredinis* were made at two locations in Manitoba, and the encouraging results to date suggest the *M. tenthredinis* may again contribute to the control of the larch sawfly (*Turnock and Muldrew, in press*).

Selection of parasite strains also may be useful where bivoltine parasites attack univoltine hosts. If suitable alternate hosts are not available, relocation or development of a univoltine strain may be possible. We also can contemplate the use of secondary and tertiary parasites to improve the effectiveness of an existing parasite complex. Secondaries might be used to reduce the competitive stress of an ineffective primary on a potentially effective one. Tertiary parasites might reduce the deleterious effects of a secondary parasite on a primary.

The opportunity to use parasites to actively enhance the effectiveness of other control measures would appear to be limited, at present, to the introduction of a parasite species capable

of acting as a vector for an effective pathogen. Such a relationship now exists between the effective introduced parasites and the virus disease of the European spruce sawfly in eastern North America (*Neilson et al., in press*). The virus introduced against the European pine sawfly lacks an effective dispersing agent and is at present effective only as an insecticidal spray (*Griffiths et al., in press*). The selection and introduction of a parasite with the ability to disseminate this virus might improve the level of total control.

The integrated control approach to the management of a particular pest species may include active measures to increase the efficacy of enemies through release and enhancement programs or may merely avoid the use of other controls that decrease efficacy. In either case, no intelligent strategy can be developed without knowledge of the composition and effectiveness of the enemies in various guilds. The selection of parasites for release programs should be based on the comparison of guilds in the donor and recipient areas while enhancement programs would benefit from comparative studies of guilds in different stands and climates.

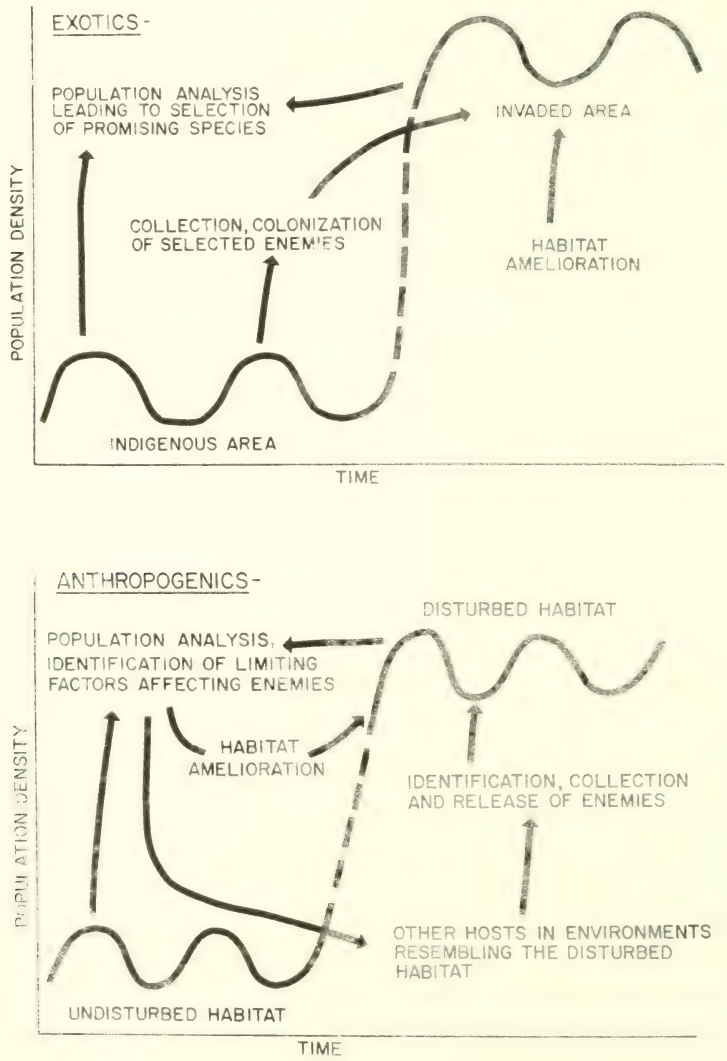
The place of parasites in integrated control operations would appear to vary with the type of pest. We would stress the importance of population analysis leading to the identification of ineffective guilds as a first step in planning the integrated control of any type of pest (fig. 1).

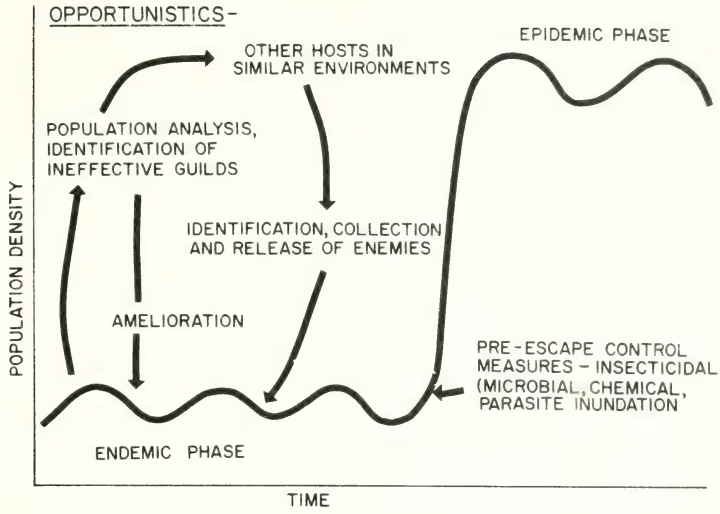
The identification and release of promising parasite species for colonization releases appears to be the most useful approach to the integrated control of exotic pests (fig. 1A). Insecticidal practices that would obstruct parasite establishment or effectiveness should be avoided. If habitat conditions in the invaded area appear suboptimal for otherwise preferred parasite species, habitat amelioration may also be considered.

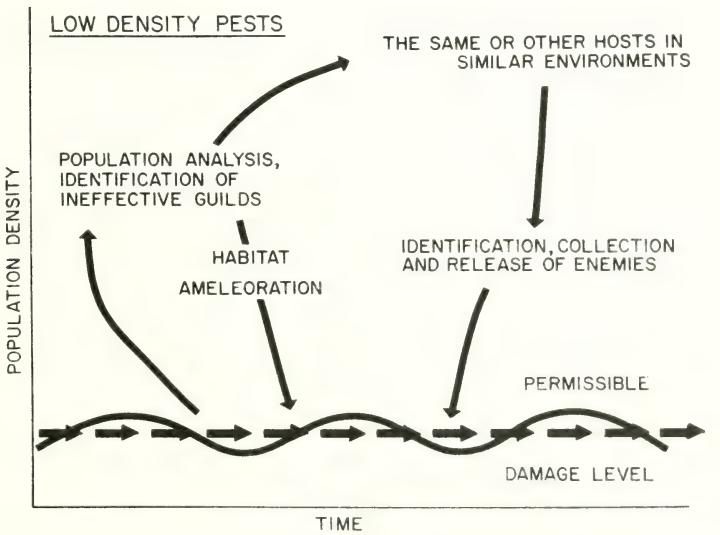
Although not all exotic pests are under effective economic control throughout their indigenous area, effective parasites may still be found for colonization releases. For example, the larch sawfly is anthropogenic in Europe while in North America it is a pest of undisturbed forests. Material for the recent release of the apparently effective parasite, *Olesicampe benefac-*

tor, was obtained in Europe from larch plantations where the larch sawfly was abundant as well as from native stands where it was consistently uncommon. Exotics that are opportunistic pests in their indigenous area may also offer an opportunity for

Figure 1.—Suggested strategy for biological and integrated control in relation to the population dynamics of four types of pests.







colonization of parasites. Here the basic assumption is that there are factors in the native home of the pest that inhibit parasite efficacy and that these inhibitors need not occur in the invaded area. Such factors may include hyperparasites, cleptoparasites (*Spradbery 1969*), predators, diseases, and competitors. In addition, differences between host trees and conditions of the physical environment in the new habitat as compared to

the native one may enhance the activity of certain parasite species.

With anthropogenic pests the main initial effort should be directed towards determining the reasons for the presence of control in natural habitats and the lack of it in modified habitats (fig. 1B). From this analysis the treatment required for rectification in the disturbed habitats may be evident. Such treatment may involve a cultural or stand-management approach or an attempt to enhance the effects of those biotic agents of control already present. It may involve a search in foreign areas for preadapted parasites of taxonomically or ecologically related hosts. Insecticidal applications will probably be necessary, but efforts should be made to ensure that the dosage and timing used are related to maximizing total control.

With opportunistic pests (fig. 1C), the initial effort should probably be on studies to determine whether the existing biotic factors, particularly those that act at endemic levels, can be enhanced. If this approach fails, a search in foreign lands for parasites of taxonomically or ecologically related species should be made. The possibility of forcing a change in the host preference of a parasite species that is not indigenous to the invaded area by cage parasitization and laboratory rearings should not be overlooked. The application of insecticides (chemical, microbial, inundative releases) during early phases of population build-up to prevent climatic release of the pest should be tested.

Since low-density pests are characterized by low-amplitude population fluctuations, (fig. 1D), improvement of the natural control complex may prove difficult. Colonization of new parasite species from other areas and enhancement of existing parasite efficacy may be possible, but the necessity for periodic control operations will probably remain. As an alternative to chemical and microbial insecticides, inundative releases of native parasites might be useful to avoid environmental contamination and application problems associated with biocides. In some cases, the most valid approach would be to promote public acceptance of a somewhat higher level of damage.

In conclusion, we would emphasize that although there has been considerable talk about the applicability of integrated con-

trol approaches to forest pest management, few attempts have been made. This approach has been successfully used against agricultural pests (see *Bartlett 1964; van den Bosch and Stern 1962*) particularly in orchards where conditions are similar to the forest ecosystem. Beirne (*1962*) suggested that neglect of the integrated approach was due to the amount and complexity of background information that must be gathered before the method becomes operational, the reluctance of growers to reduce applications of chemicals (or to suffer some damage while giving biotic agents a fair chance to build up), and the inability of proponents of opposite schools of thought to cooperate. We might also add that another contributing factor to this neglect may be that the method is still in its infancy and the knowledge and techniques necessary to enable its growth into vigorous adulthood still await discovery and development.

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INSECTICIDES

by CARROLL B. WILLIAMS, Jr., and PATRICK J. SHEA

INSECT PEST PROBLEMS have increased substantially during the past two decades in agricultural crop systems and, to a much lesser extent, in certain forest ecosystems. According to Stern *et al. (1959)*, several factors have contributed to this increase in insect pest problems: (1) the transportation and establishment of foreign pests without their natural enemies; (2) the rise of new pests due to the widespread cultivation of their favorable host plants; (3) the increasing use of crop monocultures because of their economical planting and harvesting advantages; and (4) the advent and widespread use of the inorganic insecticides, particularly DDT, to directly suppress insect pest populations.

Initially the inorganic insecticides were spectacularly successful in suppressing agricultural insect pests and insect vectors of various human diseases. However, the subsequent resurgence of pest populations to even higher general equilibrium levels, the rapid development of resistance to insecticides, and the growing contamination of the environment by the persistent chlorinated hydrocarbons showed these insecticides to be a mixed blessing (*van den Bosch 1970*). Ironically, some agricultural pests were previously effectively controlled by their parasites and predators. But the use of biotic agents gave way to DDT.

The spotted alfalfa aphid story in California in the mid-50's, the *Heliothis* and aphid story in cotton in the Canete Valley of Peru (*Kilgore and Doutt 1967*), and the apple orchards of Nova Scotia (*Pickett and MacPhee 1965*), are all examples of the consequence of relying solely on pesticides for protection of crops.

The common result of these pesticide programs was the virtual elimination of the natural enemies of the pests, followed by resurgence of the pest populations; the development of resistance to insecticides by the target pests; outbreaks of secondary pests; increasing costs of pesticides due to more frequent applications; greater amounts of pesticides per application, involving, of course, the recurrent costs of equipment, labor, and materials; residue hazards and legal complications—and still no satisfactory control. Eventually pest-management systems were evolved for a few of these pests. In each of these situations chemical, biological, cultural, and regulatory methods were used to keep the various pest populations below the economic injury levels for the crops (*Pickett and MacPhee 1965*).

Forest Insect Pests

Forest entomologists also have shown an increasing reliance on chemicals in pest control. Beginning in 1948, the spruce budworm species complex has been sprayed in various forests from New Brunswick to Oregon with varying degrees of success (*Eaton et al. 1949; Morris 1951 b; Benedict 1959*).

Epidemic populations of the gypsy moth, the Great Basin tent caterpillar, and the Douglas-fir tussock moth have also been aerially sprayed with various degrees of effectiveness (*O'Dell 1959; Benedict 1959*). Some bark beetle populations have been suppressed by applications of insecticides on the boles of infested trees (*Massey et al. 1953; Wygant 1959*).

Frequent applications of insecticides were required to bring a certain number of undamaged trees within plantations through the life growth stages when they are highly susceptible to economic injury from plantation insects such as the white-pine weevil (*Marty and Mott 1964*). European pine shoot moth, and various sawflies. Also, the increasing establishment of high-quality seed orchards required a heavy reliance on insecticides to control forest cone and seed insects (*Merkel 1969*).

Although there was a definite shift toward heavier reliance on chemicals—particularly DDT—during the last two decades to control forest insect pests, insecticides have never been as fre-

quently and consistently applied to forest ecosystems as they have been to agro-ecosystems. This is because: (1) there generally has not been the need; and (2) there is not the crop value.

There has not been the need because natural forest ecosystems, being much more complex and generally more stable than agro-ecosystems, are able to support numerous general as well as specific natural enemies (parasites and predators) of phytophagous forest insects, the category that practically all our forest insect pests arise from (*Franz 1966*). These biological control agents, collectively, have effectively dampened the population fluctuations of their hosts to the extent that most of the host insects seldom become economically important pests.

Young coniferous forest plantations resemble the simple agricultural systems. Although the insect fauna changes as plantation trees grow (*Martin 1965b, 1966; Gagné and Martin 1968*) plantation ecosystems remain relatively simple until thinning operations and other forms of tree mortality allow enough light to get to the forest floor. This permits other plant species to become established, which in turn attracts additional insect and other animal forms. Diversity in tree and other plant species and age groupings within a particular tree species helps create forest conditions such that extensive forested areas are not all equally susceptible at the same time to the same pests (*Craighead 1923*). In contrast, this high degree of susceptibility to one species of pests annually exists in agro-ecosystems.

Forest trees, being long-lived, are attacked at their various life stages by different insect pests (*Waters 1969*). Although most of these pests infrequently cause economic injury, there are several that do. It is seldom that several chemical treatments are required to get a forest stand (usually a plantation) through a growth stage vulnerable to a specific forest insect pest.

Cost Effectiveness

The valuation of annual agricultural crops greatly exceeds the annual return from forest crops such as timber and pulpwood. Consequently, the effectiveness of chemical treatments and costs of protecting these forest crops must be carefully consid-

ered. It is much more likely for protection costs to exceed the value protected in forestry enterprises than agricultural ones. Forest protection costs, as well as cultural treatments that do not immediately pay for themselves, are debits held against forest crops that may not be harvested for some time. These expenditures and the annual interest charges are carried until the value for these treatments (and there may be several) is realized at harvest time. Few businesses can afford this financial load and postponement of income. Fire, insects and diseases, and changing economies makes forestry a particularly risky business enterprise.

Insecticides should be used only in emergency situations and only when they are economically justifiable. One of the primary difficulties we have in forest insect control is determining economic thresholds for various forest pests. The economic threshold is that level of pest population that would cause economic injury without control (*Stern et al. 1959*). Economic injury is that level of damage at which the value exceeds the costs of control (*Stern et al. 1959*). Economic thresholds vary widely from area to area and depend on forest types, management intensity, and man's changing scale of economic values. Forest economic thresholds are infinitely compounded when we consider the values of the various forest resources aside from timber, such as watershed, wildlife, recreation, range, etc. Economic thresholds also depend on variations in consumer demands, and difficulties of measuring the impact of insects on yield and quality of the resource.

Environmental Contamination

Many of the insecticides applied on agricultural fields are aerially applied by planes flying close to the ground, thus minimizing spray drift out of the target area. However, environmental contamination from spraying agricultural fields is large and widespread. Insecticides affect the organisms in the target areas and are also transported through soil, air, and water to affect organisms miles from the target area. Insecticides have killed song and game birds in or near agricultural fields. Insecticides have seeped through soils and entered all water ways, re-

sulting at times in high fish kills (*U.S. Public Health Service 1961*).

The aerial application of insecticides to pest-infested forests affects not only the pest populations but also many other animals in the forest. These animals can be affected directly by actual contact with the insecticide spray droplet or residue and also indirectly through various food chains via environmental contamination. The applications of DDT against epidemic spruce budworm populations in Canadian forests have also affected the Atlantic salmon fisheries (*Kerswill 1958*) and the summer colonies of woodcock, which were subsequently exposed to heptachlor on their wintering grounds in the southern United States (*Wright 1960; DeWitt et al. 1960*). These are only two examples of non-target organisms being hurt from environmental contamination of forest insect control. The death of songbirds directly from DDT applied to elm bark beetle populations and indirectly through contamination of their food chain is yet another example (*Wallace et al. 1961; Barker 1958*).

The solution to these problems does not include the elimination of insecticides in forest insect control. If this were done at this time we would lose to those insects whose populations are not well regulated by natural factors but whose populations may frequently rise to the limit of their food supply and thereby completely deprive man of certain forest resources for a long time. Rather than propose the elimination of insecticides, we should use the ones that are currently available more intelligently and judiciously to avoid the kind of problems that have occurred in both agro-ecosystems and forest ecosystems. In this regard we also must closely examine our insecticide testing, registration, and labeling measures. We must also begin to develop more ecologically acceptable insecticides.

Ecologically Crude Insecticides

Most of the insecticides used widely today are environmentally crude. Broad-spectrum toxicological properties and marketing considerations were the major criteria applied to their development (*van den Bosch 1970*). The major objectives of the screening of these insecticides on various pests were to obtain

estimates of their killing efficiencies and residue data. Additional testing was done on an enlarged list of pests, on certain wildlife species, and on certain crop plants to determine any phytotoxicity effects. Until just recently, no data were obtained or required on the impact of these ecologically crude insecticides on the insect communities associated with the target pest populations. The importance of these data is emphasized when one recalls that insecticides used in suppressing forest insect pests were simply taken from agricultural use and applied to infested forests. Impact data are not pertinent to federal registration and the ultimate labeling of these chemicals. As a result, insecticide labels do not indicate that because of ecological impact the insecticide can, in some situations, lead to aggravated pest problems. Consequently, broader ecological criteria must be applied to the registration of broad-spectrum insecticides.

One registration requirement calls for recommended dosages of chemicals for use against various pests. There is no guarantee that the recommended dosage is the minimum effective dosage against that particular pest insect. Some of the recommended dosages for several of the organophosphates are at the upper limit of safety. If they are exceeded, serious kill of wildlife may result.

In this advanced technological country there is little reason why scientists could not predict the impact of different classes of insecticides on various ecosystems. There must be much greater understanding by chemists, entomologists, and wildlife ecologists of the interrelationships of a pesticide with soil, air, water, and living organisms to properly evaluate hazards to nontarget organisms and their environment. Each insecticide must be viewed in context with its properties, commercial usage, dosage, and the environmental effects. Predictions of the fate of each insecticide in various environments and its effects on target and nontarget organisms can be made on the basis of correlating toxicological, chemical, physical, and biochemical properties for each insecticide with the physical environment and representative phylla and orders of organisms treated. Each insecticide will differ in its uses, properties, advantages, and restrictions. We already have guidelines for evaluating the

properties of pesticides for safe use in the wildlife environment (*Kenaga 1968*).

What kind of insecticides can we design that would effectively suppress insect pest populations and still be ecologically acceptable? We have already discussed the ecologically crude insecticides that have contributed heavily to problems of resurgent, resistant pest populations and widespread environmental contamination. Obviously, there is a need for insecticides with different physical characteristics. Perhaps we can start by listing what we do not want, using DDT as an example:

1. DDT is chemically stable; half-life is more than 10 years.
2. Some of DDT's metabolites (DDE) are also exceedingly difficult to break down.
3. DDT has extremely low water solubility: less than 100 parts per million.
4. DDT is very soluble in lipids.
5. DDT is a broad-spectrum insecticide; many animal groups, not just insects, are harmed by it.
6. DDT readily forms suspensions in air and water.

The primary characteristic of DDT and its metabolite DDE responsible for most of our environmental problems is the combination of extreme persistence, low water solubility, and high lipid solubility. This combination of physical properties has allowed DDT to build up in many food chains and threaten the existence of animals at the higher trophic levels of these food chains. We can no longer apply extremely persistent insecticides to forest and agro-ecosystems. The use of persistent compounds must be restricted to product protection—fence posts, termite control, etc.

Desirable Characteristics

We think that generally we want more selective insecticides. There are insecticides that have relatively restricted toxicity range within Arthropoda. It is the broad toxicity to many groups of insects that is responsible for the elimination of the natural enemies (parasites and predators) of a phytophagous

pest along with the suppression of the pest populations. This has often allowed rapid resurgence of the phytophagous pest populations because they have been freed from the regulating effects of their natural enemies (*Kilgore and Doutt 1967*). The selective insecticides should have little effect on pollinators, decomposers, and aquatic organisms.

Selective insecticides will, for technological and economical reasons, become more costly to develop than existing broad-spectrum insecticides. But because they are ecologically selective, they will be used less intensively, effect better control of target pests, cause substantially fewer secondary pest problems, and be less conducive to the development of resistance in the pest species (*van den Bosch 1970*). Consequently, selective insecticides should be less costly to the user over the long run, and infinitely less hazardous to the general environment.

The development costs for ecologically acceptable insecticides will unquestionably be greater than those for the existing broad-spectrum, environmentally crude insecticides. Furthermore, the market potential for a given selective material will be considerably smaller than that for a broad-spectrum material.

The chemical companies will not want to bear the full cost of developing selective pesticides, and may even refuse to synthesize them. Because of this, the Federal Government may have to underwrite the development costs for the ecologically acceptable pesticides. Probably the required monies would not go directly to the chemical companies, but would be used to support critical developmental research by Federal agencies for studies concerned with the analyses of the material health hazards and their impact on the environment (*van den Bosch 1970*).

We believe the toxicity of an insecticide must be high to the target pest so that only a very small quantity of the material will need to be applied to obtain reasonable suppression of the target pest populations. In this way we can keep costs of applying it down and reduce the environmental pollution by not spraying large quantities of it per acre.

The material should be persistent enough to be available to the target pest. Perhaps its lethality should not degrade sub-

stantially before 24 hours have passed. Most insecticides that are aerially applied to forest and agro-ecosystems kill the pest by contact—either through the aerially borne insecticide droplet impinging upon the insect cuticle or the insect walking over the insecticide residue adhering to the host plants. Persistence should be long enough to allow those insects missed by the droplets to crawl over the residue and succumb to a lethal dose. The field effectiveness of DDT was due to its persistence in the habitat of the target pest insect. Unfortunately, it was so persistent that when the plant decayed, DDT was still present in the environment but no longer available to the target pest insect. In contrast, pyrethrin compounds are often much more toxic to various insects than DDT, but most of these compounds are very instable and rapidly break down into harmless metabolites. Consequently, their field effectiveness is not high. In contrast, pyrethrin stabilized for approximately 4 to 8 hours has much greater field effectiveness.

Improved Application

Another way we can increase the effectiveness of insecticides and reduce their pollution of the environment is by improving our application of the materials to the pest-infested crops. Application techniques are just as important as the insecticide. The chemical is just one factor in a complex system that includes spray physics and equipment, the timing of application, and a thorough knowledge of the weather conditions during the spray operations, as well as a complete knowledge of the target pest and its most susceptible stage.

It is important that a contact insecticide be applied during a period when the majority of the insect pest population is exposed. For many defoliating insects, this is during the larval stage, particularly at the large or late larval stage. Frequently, about 75 percent of the food consumed by insect larvae is consumed during the last larval instar. Also, it is not wise to spray when parasites of the target pest are vulnerable. Consequently, compromises are sometimes required between applying the insecticide when the target insect is most exposed to obtain a

very high population kill, or applying earlier in the larval stages of the pest to save as much foliage as possible, realizing that you would obtain less population kill, but at the same time would protect the parasites of the target pest.

Application of the insecticide must be made to assure that the target area is adequately covered—that no areas are missed and that few overlaps occur. Well-marked spray boundaries and preplanned flight lines are very helpful. Observation planes are useful in guiding spray planes during their runs to note the drift of the insecticide clouds, thermal updrafts, and missed areas.

Atmospheric conditions must be right for the aerial application. Spraying is usually done early in the morning when the wind speed is less than 5 m.p.h. and there are no thermal updrafts caused by the sun warming the slopes. Spraying is discontinued when the wind speed or turbulence increases, because excessive drift of the spray cloud will cause areas to be missed and contamination of nontarget areas to occur.

Recent research indicates that practically all the insect mortality in an aerial application is caused by spray droplets that are below 50 microns in size when they contact the target insect (*Himel and Moore 1967*). In the past, spray droplets of this size usually represented a small portion of the spray droplet spectrum and contained approximately 5 percent of the spray mass. This means that 95 percent of the spray mass in droplets over 50 microns was wasted and contaminated the environment. The magnitude of this waste is illustrated by the fact that doubling droplet diameter results in an eightfold increase in volume. That is, a 100-micron drop contains 8 times as much insecticide as a 50-micron drop. It is simply a matter of spray physics—double the size of the droplets and you cube their volume. The insect larvae are screened by foliage, limbs, tree trunks, and silken threads, which filter out the larger spray droplets. Possibly those droplets 50 microns and smaller that reached the forest canopy were slightly repelled by the small magnetic fields surrounding the foliage and small limbs, filtered through the forest canopy, and scored direct hits on the insect larvae.

These spray droplets 50 microns and under in size have been referred to as aerosol sprays. Weather will be an important

factor in aerosol spraying. Air currents can be used to deliver the spray to the target area by a process called atmospheric transport and diffusion (A. D. Moore, 1967; personal communication). Atmospheric diffusion is accomplished when the aerosol spray is spread out laterally over a drainage like a flat cloud. This occurs when the air is still under inversion conditions.

Atmospheric transport is the movement of the spray cloud down toward the ground into the tree crowns. This is accomplished when the sun begins to warm the east-facing mountain slopes early in the morning. As the low-lying air warms up and begins to rise, it is replaced by air moving in. A mixing or looping effect occurs, which sends the spray droplets into the tree crowns several times at various angles. Therefore, we need to develop spray equipment that will discharge the spray mass in that portion of the droplet spectrum that is most effective in reaching and killing the target insect. The timing of the spraying application must be at the optimum stage when the target pest is vulnerable; and its parasites and predators must be protected before substantial economic injury occurs. The spray must be applied in a manner conducive to reduction of environmental contamination.

Strategy of Pest Management

Not only are insecticides and application techniques important factors in a pest-management system, but also pest control strategies should play an increasing role in pest management. Research in the population dynamics of various pests and in the growth and development of their host stands should provide data from which we can construct models describing pest and resource systems. Reliable models will describe the behavior of the pest system responding to its natural mortality factors. These models should describe the interaction between various pest population densities and the forest system. Simulation studies involving the interaction between these systems need to be run through many simulated insect generations to determine what happens to both systems at different population levels and various forest-stand damage histories.

These simulation studies should: (1) determine the effects of various pest population levels on current and cumulative damage in the absence of and with varying degrees of chemical control; (2) describe the effectiveness of various natural mortality factors at different pest populations in the absence of chemical controls; (3) determine which mortality factors are key factors under various simulated forest stand conditions; (4) affect various levels of insecticide-induced mortality on the pest populations to describe the effectiveness of natural mortality factors at these different pest population levels with the added presence of the insecticide and its impact on the environment; (5) determine the cost effectiveness of various classes of insecticides on the pest populations and the forest stands; (6) determine the impact of these various classes of insecticides on certain nontarget organisms and the environment; (7) determine the optimum timing of various classes of insecticides that will minimize the hazards to the parasites and predators of the pest and maximize crop protection; and (8) determine the minimum pest population levels needed to maintain effective parasite and predator activity.

Various pest-control strategies can be developed from information obtained from these simulation studies. We must know what happens to forest stands infested by various pest population levels for different periods of time. We must be able to predict the effectiveness of various classes of pesticides and their hazards to the environment, based on their properties, the pest population levels, and the type and conditions of the infested forest stands.

We must apply the insecticide in such a manner that it has little effect on the other mortality factors affecting the target-pest populations. This means that the insecticide by itself may not be applied at a time that could result in maximum pest mortality. Certain constraints like the vulnerability of effective parasites and predators at various stages of the target pest's life cycle would require insecticides being applied at a time when these natural enemies are less vulnerable even though the timing of the spray application is such that the pest is also less vulnerable to the insecticide. The goal in pest management is

not pest eradication but the maintenance of pest population levels below the economic injury levels of our various resources.

Possibilities of Integrated Control

Since forest pest-control specialists are returning to an ecological approach to pest control, consider the general possibilities for using integrated control on several groups of insects.

The large investment necessary for the establishment of orchards comprising superior genotypes of various tree species for the purpose of high-quality seed production must be protected. The economic threshold for these orchards is quite low. Until more is known about the biology and population dynamics of cone and seed insects there will continue to be a heavy reliance on relatively persistent insecticides to suppress cone and seed insect populations in these orchards.

Since there is little or no investment for seed production in natural forests, there is little need for control of seed and cone insects. The economic threshold for seed production is very high.

The large investment for nursery establishment and production must also be protected. Integrated control of nursery pests is obtained by judicious nursery practices emphasizing hygiene, planting schedules, and various spot pesticide treatments (*Franz 1966*). Environmental contamination from the use of pesticides should be low.

The investment in plantation establishment can be won or lost depending upon the tree species planted and the site quality of the land. For example, the white-pine weevil precludes the planting of pure stands of eastern white pine throughout its botanical range. Shoot and tip moths endanger many plantations of hard pines in the eastern and southern United States. In contrast, many plantations of Douglas-fir in the Pacific Northwest thrived. So far, there has been little or no research on the population dynamics and parasites and predators of our plantation insects. Except for some virus diseases in some sawfly populations, biological control seems ineffective (or undeveloped) for most plantation insects. Varying the spacing of

seedlings—and subsequently stand density—may help decrease the damage from white-pine weevil and European pine shoot moth.

The mistake of planting large areas to pure stands of white pine and red pine should be avoided in the future. However, for the time being, many plantation owners rely on insecticides to bring through enough undamaged trees to make a profitable crop through the growth stage of susceptibility to plantation insects. Examination of old plantations formerly infested with shoot or tip moths frequently reveals that many trees, now pole-size, have outgrown deformities caused by these insects. Slow-growing trees on poor sites take longer to grow out of stages most susceptible to plantation insects. All in all, there appears to be an undeveloped opportunity for effective integrated control.

The combined use of silvicultural cutting techniques and pheromones, insecticides, and chemical sterilants promises an effective integrated control program for bark beetles within the *Dendroctonous* and *Ips* species complex.

Silvicultural techniques such as diversifying tree species within a forest stand and age groups within a tree species, can result in a mosiaic forest stand in which only a few portions are highly vulnerable at the same time to bark beetles. Risk-rating schemes such as the Keen classification and prompt salvage of blowdowns and rapid harvest of overmature stands helps to prevent bark beetle population build-ups in the most vulnerable trees.

The phermomone work offers the great possibility of attracting the beetles to a trap in which they may be killed by insecicides or sterilized by other chemicals. Some research breakthroughs are imminent.

Research is progressing on the population dynamics of various bark beetle species. The effectiveness of various parasites and predators is being assessed. There may be opportunities for manipulating these biotic agents to increase their effectiveness.

Generally speaking, the possibilitities of using integrated control on forest defoliating insect populations is good. Many of

the insects are effectively controlled by parasites and predators and only occasionally become numerous enough to require the application of insecticides. Current research on the population dynamics and sex pheromones of the most economically important insects promises substantial payoffs.

Some possibilities of an integrated control program for the most economically important forest defoliating insects are presented below.

Spruce Budworm Species Complex

Implicit in any ecological approach to pest control is knowledge of the biology and population dynamics of the insect itself. The spruce budworm species complex is widely distributed in North America. It spans the North American continent with representatives in many different forest types. It has been divided by T. N. Freeman (*1967*) into nine species.

The spruce budworm *Choristoneura fumiferanae* (Clemens) is the most widely studied forest defoliating insect pest in North America. A large portion of some of the most classical work in forest entomology has been done on this insect (*Morris 1963*).

A substantial amount of information exists on epidemic dynamics of *C. fumiferanae* in a few forest types. The majority of Canadian and American studies have been on epidemic populations of this insect in eastern North America balsam fir-white spruce forests. More work is needed on other *Choristoneura* species in other forest types. Although research on the 2-year budworm *C. biennis* populations in Canada has been published (*Shepherd 1959*), additional studies on *C. occidentalis* populations in Idaho, Montana, and the Pacific Northwest are necessary.

Very little published information on endemic population dynamics exists for any forest types. Biotic factors may be more effective in regulating low or endemic populations than high populations.

Several environmental factors seem to permit outbreaks of the eastern spruce budworm (*Choristoneura fumiferanae*) and the western budworm (*C. occidentalis*).

Dense populations of *C. fumiferanae* are associated with flowering of balsam fir, large areas of essentially pure balsam fir, mature and overmature balsam fir in mixed stands. White, red, and black spruce are also hosts. Spruce budworm larvae development may be more rapid on white spruce than on balsam fir.

C. occidentalis primary hosts are true firs, Douglas-fir, and Engelmann's spruce. Budworm-susceptible forests are increasing in Western States due to the logging of ponderosa pine and forest succession from pine to firs in the absence of fires. Population dynamics of *C. occidentalis* on true firs may be analogous to that of *C. fumiferanae* populations on balsam fir.

Hot dry weather is the key factor in large budworm outbreaks. Hot dry weather increases flowering in balsam fir trees over large areas, thereby resulting in optimum food and shelter for small budworm larvae. Budworm development, feeding activity, and survival are greater during hot dry weather. Any forest type and stand structure that allows high evaporation rates and increases crown exposure favors local survival of large budworm larvae regardless of regional weather.

It is desirable to identify, evaluate, and manage epicenters or reservoirs of pest populations, particularly when they are small in relation to the total potential infested area. Identification of epicenters has been done from time to time:

1. Lake Nipigon, Ontario—the area from which the huge outbreak during the early part of this century originated and gained momentum. Mature stand of balsam fir is now present.

2. Colorado Pass-Clearwater area Idaho—Montana. Budworm populations on grand fir sprayed five times to no avail as populations regained epidemic status within 2 years after spraying.

3. True fir concentrations in the Wallowa Mountain Ranges of eastern Oregon were the epicenters from which the 1945-55 budworm outbreak spread in Wallowa County.

Silvicultural Control

One of the procedures we may employ in manipulating the environment to make it less conducive to budworm population build-up is forest cutting. We usually call this procedure silvicultural control. The following is what might be attempted using this procedure. Many of the suggestions for eastern North America are well documented in the literature (*Morris 1963*).

In eastern North America:

1. Reduction of balsam fir complement in forest stand. Encourage less budworm-susceptible conifers and some hardwoods to achieve diversified forest types, thereby breaking up continuous canopies of balsam fir.

2. Cutting large overmature trees, and planning short rotations for pure balsam fir stands and mixed fir stands. The cutting units should be kept small (40 to 60 acres) and arranged to attain a diversification in age classes between adjacent units in succeeding balsam fir forest stands. Controlled burning and scarification of the forest floor should be practiced to destroy the advanced balsam fir regeneration and expose the mineral soil to increase the complement of white spruce in the succeeding forest stand.

In western North America:

1. Reduction of the true-fir complement in all budworm-populated forest stands.

2. Cutting Douglas-fir and burning cutting units to favor ponderosa pine over all firs.

Patch clearcutting with cutting units kept as small as practicable should be used to increase first- and second-instar budworm dispersal losses. The highest mortality of the generation occurs during these dispersal periods. During dispersal periods larvae are more likely to land on host trees in a dense stand than in an open stand.

Biological Control Procedures

Parasites, predators, and diseases do not appear capable of suppressing epidemic spruce budworm populations (*Morris 1963*). However, some of these agents may be more effective at low or endemic budworm population dynamics and consequently our need for additional work is again illustrated. In any case, full control by parasites and predators is a biological rarity.

It may be possible to increase the complement of the seemingly ineffective natural enemies of the budworm. Perhaps some of the potentially more effective parasites are regulated by alternate hosts. Regardless of present levels of knowledge on parasites and predators, insecticide application, if possible, should be timed to avoid periods when the parasites are emerging and flying. Chemical procedures must be used in a manner that is least disruptive to biological control of actual and potential pests.

Chemical Procedures

Insecticides have been the main control used in our attempts to suppress spruce budworm populations.

The spruce budworm is the most destructive forest defoliating pest in North America. As a result more acres of budworm-infested forests have been sprayed than for any other defoliating pest in North America. Since 1949, tree mortality resulting from spruce budworm outbreaks has been reduced through extensive aerial spraying programs, using various formulations of DDT on budworm-infested forests in the United States and Canada.

Although generally good direct control of *C. occidentalis* population has been obtained by aerial application of DDT at an average cost of $1.00 per acre, widespread concern has grown over the adverse effects of residual DDT against nontarget organisms. This concern prompted some Federal agencies to discourage and frequently ban the application of DDT on Federal forest lands. Also there is evidence that spruce budworm populations in New Brunswick were developing more resistance to DDT formulations (*Randall 1965*).

Programs were set up to seek safer, more specific, and less

persistent insecticides to replace the wide-spectrum, environmentally persistent DDT (*Moore 1964*). Some of the insecticides tested in that program—DDD, Korlan, Sevin, and Malathion—were not as effective as DDT against the spruce budworm at similar dosage levels. Phosphamidon is effective against the budworm and is only 1/40th as toxic as DDT to young Atlantic and Pacific salmon. But it is extremely toxic to birds. Laboratory and field tests show that one of the most promising insecticides for budworm control is a carbamate called Zectran. Zectran appears to have many of the characteristics sought in the basic chemical. It is 100 times more toxic to spruce budworm in the sixth instar than DDT and hence can be applied in small amounts not hazardous to other forms of life. Zectran is especially safe to fish, birds, and small mammals. It is also nonpersistent, breaking down in sunlight within a few hours.

Since Zectran does not possess the persistence of DDT, a characteristic that contributed significantly to the field effectiveness of DDT, the application procedures must be re-evaluated and updated to take advantage of the physical characteristics of Zectran. Target selectivity and percent mortality can be increased by the manner in which the insecticide is applied.

Quite clearly, differences in persistence mean differences in the probability of contact with the target pest when comparable methods of application are used. The probability of contact can be increased by employing any combination of the following procedures:

1. Increasing the number of applications in a season.
2. Increasing the amount of toxic material per acre in an application.
3. Increasing the amount of carrier in an application.
4. Modifying the droplet spectrum to yield higher proportions of the insecticide in the effective droplet size range.

First, most of the insecticide applied in past programs was wasted in large drops that did not hit the budworm but contaminated the environment. Recent research shows that droplets below 50 microns are most effective in causing budworm mor-

tality. About 97 percent of the droplets found on dead larvae in field tests were below 50 microns (*Himel and Moore 1967*). Spray equipment is now being developed to produce droplets below the 50-micron size at the target insect. (Missouri Equipment Development Center, USDA Forest Service, Missoula, Montana.)

Second, these small droplets are carried to the budworm larvae by atmospheric transport and diffusion much more than the larger droplets, which are more apt to be filtered out by the forest canopies. Strict attention must be paid to normal diurnal wind patterns in the drainages to be sprayed in order for the cloud of insecticide to be more accurately directed to the target insects.

Large-scale field tests on which Zectran was applied at an average concentration of 0.15 lb. in 0.73 gal. of cycle oil: Methylene chloride (9:1) per acre showed that the material is capable of reducing budworm populations by 90 percent or better. These field tests also showed that Zectran is relatively specific in its action by reducing budworm populations to a much greater extent than most populations of insects associated with it in tree crowns (*Williams and Walton 1968*). We have differential mortality that favors nonpest insects.

The ratio between parasites and host was radically altered by Zectran. Budworm larvae parasitized by the overwintering parasites *Apanteles* sp. and *Glypta hariolus* survived the applications of Zectran proportionately better than unparasitized budworm larvae and larvae parasitized by other parasites (*Williams et al. 1969*). Consequently, the incidence of parasitization expressed as the number of parasites per 100 budworm larvae increased after the insecticide application.

It may be possible through integrating these various control procedures to keep budworm populations below the economic level by:

1. Reducing or converting budworm-susceptible forest types through logging and control of species composition by logging and burning.

2. Attaining a diversification of species and age classes to re-

duce the component of susceptible species and age groups in the stands. The frequency of budworm outbreaks in an area may thereby be reduced.

3. Judicious use of a nonpersistent and relatively specific insecticide on budworm outbreaks that do occur, to increase the incidence of parasitism in the budworm population, yet not to decrease the population's alternate hosts of the parasites in the environment proportionately more than the budworm. This type of development should increase the parasite pressure on the next budworm generation and hopefully this situation would endure for several budworm generations. Identification of those areas where the pest-parasite ratio is unfavorable and proper timing of chemical application is important.

It is no longer necessary or even desirable to achieve a high percentage of mortality (usually 95 percent or greater) of the pest population as has been the goal of past pest-control programs. Although there has been no analysis of the results of aerial spraying experience against spruce budworm, it is clear that a rather large, well-organized segment of forest industry in eastern Canada has found, through extensive spraying experience, that sacrificing high percentage mortality for good foliage protection is an acceptable strategy for control operations. We recognize that this objective may not be optimal but conclude that it is acceptable at least in some economic circumstances, and consider levels of population reduction near to and higher than the levels that have been accepted in eastern Canada.

In some control situations we may be satisfied with a mortality of 90 percent or lower so that we do not disrupt but perhaps enhance biological control action where the pest-parasite ratio is unfavorable. A high mortality percentage is not important *per se*, but a residual and subsequent population regulated below the economic damage level should be the goal.

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INTEGRATED CONTROL, PEST MANAGEMENT, OR PROTECTIVE POPULATION MANAGEMENT?

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THE PREOCCUPATION of foresters and forest entomologists in suppressing populations of phytophagous insects competing for the forest resource has led to the establishment of several "territories":

Mechanical control.—Mechanical methods such as burning or felling, and peeling and burning the bark of trees infested by bark beetles.

Chemical control.—Applying insecticides.

Biological control.—Utilizing predators, parasites, and diseases. Classical biological control emphasized the use of introduced parasites, predators, and diseases for exotic insects.

Silvicultural control.—Utilizing silvicultural and management practices.

Ecological control.—Includes not only biological and silvicultural methods but also selection of genetically resistant trees.

To this list should be added the new definition of biological control. Biological control now encompasses all methods of control that can be considered biological in nature—excluding chemical and mechanical.

Two more definitions of control came into being more or less simultaneously: harmonious (*Voute 1964*) and integrated (*Smith and Allen 1954*; *Stern et al. 1959*). Both were a consortium of territories.

Harmonious control.—A synthesis of ecological, chemical, and eventually mechanical. It includes integrated control. It is the

most many-sided idea of control of insect pests possible. The application of pesticides is not abandoned, but is intended for use in addition to other methods since it is explicitly stated that chemicals should not interfere with natural population regulators.

Two definitions of integrated control are necessary, first to establish proper priority, and second to define its current status.

Integrated control.—The earliest definition of integrated control (*Smith and Allen 1954*) recognized the necessity for consideration of the ecosystem; but social, political, and economic pressures necessitated an immediate reconciliation between chemical and biological control. The definition arrived at by Stern *et al. (1959)* was more palatable at the time to growers and industry. This was: "applied pest control which combines and integrates biological and chemical control." As techniques improved, the benefits of minimizing pesticide use became more apparent, and the hazards of intensive use of chemicals more obvious; and the broader concept of integrated control evolved.

Smith (*1969a, b*) said: "Integrated control is a pest population management system that, in the context of the associated environment and the population dynamics of the pest species, utilizes all suitable techniques and methods in as compatible a manner as possible and maintains the pest populations at levels below those causing economic injury."
and, further:

"Integrated control is an ecological approach to the control of harmful pests. It derives its uniqueness from emphasis on the fullest practical utilization of existing mortality and suppressive factors in the environment. Its strategy is one of 'management and containment' rather than 'seek and destroy.' The goal of the integrated control system is to provide a stable and economically sound procedure for crop protection."

There are two principles common to both these definitions, but particularly the later one, without which the definitions are incomplete. These are: (1) consider the ecosystem, particularly avoiding disruptive actions, and (2) utilize critical injury levels.

By agreement, at various international symposia, integrated

control is used in appropriate literature rather than harmonious control. I think it is obvious at this stage that there is a drawing together of ideas concerning pest regulation.

The concept of utilizing natural enemies and forest cultural methods to minimize damage by forest insects is deeply rooted in European forestry (*Voute 1964*). Those chemicals used were natural compounds, and biologists were more or less forced to study natural causes and treat accordingly. When broad-spectrum insecticides appeared they were utilized but with far more respect for the environment than in North America. The store of fundamental knowledge built up over the centuries in the care of their forests was not neglected as it has been in North America. Verbal formulation of the concept of harmonious control began about 1958.

In North America, faced with a superabundance of forest resources, early foresters were little concerned with the relatively minor losses inflicted by forest insects or diseases. It was not until late in the 19th or early in the 20th century, when large capital investments in physical plants were made, that losses in the vicinity of those industries became of concern. Then the myth of superabundance was replaced by the myth of supertechnology, encouraged by the apparent success of lethal insecticides in agriculture. Initial apparent successes in "pest control" led to what Graham (*1964*) refers to as "preoccupation with procedural aspects". A type procedure was adopted for each situation as it arose, and the underlying manipulations were largely ignored.

Meanwhile, the agriculturists were learning that the use of a single kind of control procedure was not solving the problem. Indeed, new and more serious problems were evolving, and integrated control in its narrow sense evolved (*DeBach 1951*); *Griffiths 1951; Pepper 1955; Pickett et al. 1958; Ripper 1944, 1951; Smith and Hagen 1959; Stern et al. 1959*). Although most ecologists and entomologists had long embraced the ecological approach to pest regulation, it was not until evidence accumulated on the harmful side effects of pesticides and public reaction and opposition to their use increased, that the broader and more inclusive concept began to be promulgated and accepted

(*Chant 1966a; FAO 1966, 1968; Geier and Clark 1960; Smith 1963, 1968a, 1969a; Smith and Reynolds 1965*).

The concept of integrated (harmonious) control grew out of forestry practices in Europe and agriculture in North America. There have been to date only token efforts to apply the system in forestry. Early forest entomologists and biologists preached the lessons learned from European foresters, but their sermons fell largely on deaf ears. If one goes to texts of S. A. Graham, Hawley and Stickel, and others he will find the seeds of the "integrated control" concept planted there. They are only now beginning to show signs of germinating. Smith (*1963*) and Franz (*1965*) are among the most recent to propose that we fertilize them.

However, the situation is still in a state of flux. Several recent authors have proposed another way of looking at this whole problem of protecting our forest resource from its enemies. Since the forestry profession, as I see it, is on the brink of embracing something along this line, I think it behooves us to examine this concept. We may not have to tread in every footstep the agriculturists have placed before us—perhaps we can skip a few. I refer, of course, to the concept of "pest management", or "protective population management".

Geier and Clark (*1960*) coined the term "protective population management". They argued that a continuous sequence of ad hoc programs of destruction of noxious insects has occupied available personnel so that they have ignored fundamentals of ecology, including socio-economics—which is really ecology. In practice, there is no real difference between their definition of pest population management and integrated control. Geier (*1966*) shortened the name to "pest management" and stated:

> [it] was coined to emphasize the comprehensive nature of the approach and to underline its preoccupation with ecological realities. It is intended to convey the idea of intelligent manipulation of nature for man's lasting benefit. The greatest single quality which the new strategy should possess is selectiveness in its action on a specific population. This selective action must remain at all times commensurate with population's potential injuriousness. To achieve that, the new approach must aim, above all, at making control operations fit well with the biology of the noxious species.

It should be noted that in a truly ecological sense no manipulation of the environment is truly selective. Beirne (*1967*) broadened the concept of pest management:

> Pest management is one of a number of more or less analogous terms that refer to management of aspects of the environment in ways that will benefit our interests . . . [It] refers to actions at a different level, actions that are primarily aimed at harming living organisms that are harmful to us or to resources that we use. . . It consists of the intelligent management of pests and of their surroundings and the management of the people who devise or do that managing. The management of pests is commonly what is meant by the term pest control.

Authors have in recent years begun to use the terms pest management and integrated control interchangeably. For example, the index of recent publication of the National Academy of Sciences "Insect Pest Management and Control" (*1969*) has the curious section heading "Successful Unilateral Pest-Management Systems".

Chant (*1966b*) suggested that pest management and integrated control are synonymous. Smith (*1968b*) used the term pest management almost exclusively when discussing the ecological approach to pest regulation and mentioned the social and political ramifications. However, although the rationale of both are practically identical and the guidelines for integrated control (*FAO 1968*) can be incorporated as a part of the guidelines for pest managers, I feel we should consider pest management and integrated control as two distinct entities. Pest management should be considered as a component of resource management (*Watt 1968*). Integrated control is the approach by which regulation of pest populations is achieved, whereas pest management is the decision-making process where all aspects such as societal values, impact on other resources, and the like are considered prior to making the decision whether population regulation is to be undertaken.

Management of Pests

One of the fundamental principles of integrated control can be transposed intact to pest management: "utilize critical injury levels" (*Smith 1969a*). This has been variously named economic

threshold (*Stern et al. 1959*), action threshold (*Chant 1966a*), and economic injury level. The intent is clear, but the application in practice is not simple and requires examination in the forest environment.

The concept of economic threshold as developed for agricultural entomology is not adequate for most decisions in management of forest pests. It was developed along strict profit-loss relationships and does not include sufficient recognition of forest ownership and mixed values.

There are approximately 773,400,000 acres of forested land in the United States, 461,044,000 of which are classed as commercial. If an insect problem occurs on the noncommercial forested land, how do the economic considerations of marketplace values on which most of our evaluations are based apply? Of the commercial forested land, approximately 106,071,000 acres are under public guardianship, either federal, state, or other. Portions of this land are designated as national forests, national parks, wilderness areas, and other types of reserves, administered by a variety of agencies. Again, how do you apply *economic* thresholds compatible with the multitude of uses involved? Of the remaining commercial land, about 350 million acres, an estimated 59 percent, is in scattered nonindustrial private holdings that are either not managed at all or only slightly so. How can you apply *economic* thresholds to land that is not managed for its crop? The economic threshold is defined as the density (of the pest population) at which control measures should be determined to prevent an increasing pest population from reaching the economic injury level. The economic injury level is the lowest population density that will cause economic damage (*Stern et al. 1959*). Use of this concept is, at best, feasible only for that 150 million acres under management for forest crops.

Johnson (*1963, 1966*) and others have addressed themselves to the problem of determining economic thresholds under various commercial forest situations and have pointed out that even where a single ownership is involved and the kind of crop is fixed, the task of determining the benefits derived may be far from simple. A forest crop such as a nursery or a Christmas

tree plantation approaches the agricultural situation, and the techniques of establishing economic thresholds can be applied with justification. But if the crop depends on a harvest 80 years from the time of planting, how can you apply today's marketplace values and control costs to a product (for example, lumber) that not only fluctuates markedly in value for top-grade products but just as widely depending on the quality?

In most commercial situations in forestry the "economic thresholds," where they are set at all, are set arbitrarily and are dictated largely by emotional responses—fear of what might occur rather than any justified economic base. The many absurd "control projects" committed in the name of protection are possible only through government subsidy. Outbreaks that truly jeopardize commercial managed forests are rare even in apparently susceptible uniform forest types: where they occur they rarely proceed unchecked to eliminate entire forests. The chief malefactors, bark beetles, although they may cause cessation of growth (death) of significant portions of the stand, do not destroy the crop. It remains there, amenable to harvest, should the management plan be flexible enough to utilize it (*Johnson 1940*). Also, much of our forest economy is geared to a single product. Where the product is only lumber, a dead tree, blue-stained and invaded by secondary insects, may be a total loss; but in a multiple-use industry, most of the tree may be recoverable.

The emotional response to insect kill and damage is often unrealistic, as is the attitude that we must give away, in the name of control, perfectly valuable ponderosa pine, Douglas-fir, sugar-pine, etc., killed by bark beetles. Occasionally, as in catastrophic storms with the incipient insect consequences, this may be justified; but the annual sales of bug-killed trees and adjacent green (infested or not) timber at prices far below going prices and additional tax benefits seems to me questionable.

It is not unlike the situation existing in the cotton industry. Annually the Government spends millions of dollars for landowners *not* to grow cotton. At the same time, research agencies, growers, and the Government spend millions to protect what cotton is grown! It would seem to me that if a national policy

were developed that would permit rotation of crops over the total range of cotton land, a balance might be achieved with cotton plants, insects, and national production goals. If restricted to cotton lands, subsidiary industries would not suffer unduly as it is unlikely that in any particular area no crops could be grown. For those growers who could demonstrate a financial loss from changing to another crop, an indemnity replacing the no-grow subsidy would suffice.

Another example of abuse of the economic threshold concept is the spruce budworm problem in eastern Canada. The vast acreages over which control has been attempted often have little relation to the economic interests involved. The areas covered by such control, and this applies to budworm control in Montana and Washington as well, if on commercial land at all, usually exceed any that might conceivably be utilized in a lifetime. There would be ample time for a replacement crop to mature—assuming the budworm did its worst. Protection of a national resource is then invoked. A type procedure—chemical spraying—is adopted, and a private corporation is formed to carry out this procedure. This would seem to be the acme of "Graham's Law" (*1964*), to the end that once a type procedure is adopted for a type situation it is pursued inflexibly without thought of what it is actually contributing. The dissolution of a public corporation or a government bureau because of obsolescence is a difficult feat to accomplish!

Many authors have stated that we do not have realistic estimates of the impact of insects in forests upon which to base treatment decisions. There is confusion between injury and damage (*Smith 1968c; Strickland and Bardner 1969*). Injury consists of the actual acts of insects, which cause damage to the plant. This damage varies according to insect numbers and behavior. Plant damage is the effect on the plant of the insect injury and may or may not result in crop loss (e.g., beneficial thinning by bark beetles may actually increase yield). Damage may take several forms, such as loss of growth, direct mortality, reduction in quality, and destruction or deterioration of finished products. This determination of realistic estimates of damage is the most urgent item in forest pest management today. I

suspect that we will find that we have little justification for most of the past and existing control programs—at least in the manner in which they are executed.

In an industrial situation it is apparent that the benefits from specific pest-control actions should exceed by an adequate profit margin the total costs of such actions. This cost-benefit ratio should include long-range costs such as costs of treating secondary pest outbreaks, costs of sorting or handling the final product, and supervisory charges. Agriculture, in general, ignores long-range costs—but foresters cannot. The long-range costs or even reasonable estimates of them are usually not available at the time the decision must be made. Unfortunately also, the decision-maker, even if aware of them, may feel that the long-range costs need not be accounted for by him, but will be paid for by the succeeding generations or a remote government or society. Hence, unfortunately, most control decisions at the individual producer level are made on a very short-term basis and at current market values. Since in forestry situations insect control is heavily subsidized by the Federal and state governments and decisions usually rest with them, it would seem that this would be amenable to change.

I repeat that the necessity for taking a hard look at our justifications for control is our most urgent task, and it has always been a matter of wonder to me (and lately slightly of suspicion) why forest economists have, in general, ignored this problem. I think the techniques for developing economic criteria for at least industrial forest lands are available. I believe the use of the life-table approach adapted by Waters (*1969*) married to the systems-analysis techniques of Amidon (*1966*), Hill and Amidon (*1968*) and Davis (*1968*) with existing data will provide realistic figures in industry-oriented forests for those forest insects currently considered pests. What is required is that a pest manager and a forest manager integrate their respective resources and talents to that end.

To this point I have limited this discussion of "economic threshold" to industrial forest land, essentially "cost-benefit" relationships. The greatest bulk of forested land is not in "production" in the strict sense, and although I do not have fig-

ures, I would hazard a guess that as many control efforts are on this public land as are on private. The criteria for control decisions on public land dedicated to various uses is infinitely more complex than on industrial land.

The most comprehensive example of the problems involved is given by Vaux (*1954*), who discussed the economic implications of a vast control project involving the outbreak of Engelmann spruce beetle in Colorado. The justifications invoked (and which are commonly invoked by forest entomologists) were protection of watershed values, recreation values, and timber utilization. Assigning economic values to the first two is an exercise in frustration. It may never be possible.

Rather than attempt to commercialize what are essentially sociopolitical problems, why can we not assign "critical injury limits" based on a risk-benefit ratio (*Starr 1969*) where the risk to that particular enterprise is evaluated not in dollars but in relation to its continued efficiency in that particular function? For example, the most efficient watershed is probably paved so there is no loss by transpiration and interception. The water is conveyed immediately to covered storage ponds in the valleys, and runoff is regulated by valves. Although not well documented (which means I could not find any references), the belief exists and is growing that heavy forest (tree) cover is not particularly efficient in terms of water production. Perhaps insect kill or heavy defoliation may actually be beneficial in terms of water supply. Additional risks to be considered, however, would be increased fire hazard, increasing protection costs, and perhaps less efficient flood control.

Some economic values can be assigned to recreation—for example, fishing and hunting permits, increased number of tourists, average dollars spent, etc.—but these so overlap and depend upon so many intangible values that to assign the value to the forest or lack of it alone would be misleading if not false. Does the presence of extensive budworm defoliation or beetle kill really affect recreation possibilities? Does it really discourage people from visiting forested areas? My experience in Canadian and Californian national parks indicates that if such damage has any effect, it is negligible. In fact, in Yosemite Na-

tional Park, the Ghost Forests of Tioga created by a needle miner outbreak is an attraction!

The spruce bark beetle outbreak was mentioned above. According to Vaux (*1954*), a separate economic analysis of the area indicated that the timber area affected constituted a poor investment risk. The appearance of the area affected, including untreated areas that have undergone extensive beetle outbreaks in Canada and California lead me to state that apparently such outbreaks created no material effect on watershed or recreation. What is required in pest management is an extremely broad perspective in assessing risk from outbreaks on noncommercial lands. The pest manager must look at the area from at least a regional view, if not national. Consideration of land allocation must be included. For example, the Rocky Mountain States are the least productive part of the United States for timber production (*Wagar 1969*). Northern Idaho and western Montana already have more industrial plant capacity than can be kept supplied with current levels of timber management. Old-growth stands once permitted (without management) a profitable industry, but this is not true today. This has created a pressure to permit use of old-growth stands locked up in national forests. Whether this comes to pass or not, it merely prolongs the situation. On the other hand, these same areas are extremely rich in watershed and potential power sources for the Northwest and Central States and in recreation potential. My point is that the pest manager, in concert with the forest manager, should examine land use in this context.

One last example of the necessity for broadening the scope of pest management to be included in the resource-management level is closer to home. The research forest of the University of California is located in a highly productive mixed conifer forest. A recent study (*Teegarden and Werner 1968*) presented a case history of integrating forest-oriented recreation with timber growing. They pointed out that under certain conditions conversion of timberland to vacation homesites was a profitable venture. Lacking in their analysis was consideration of costs for protection from bark beetles. Since bark beetles are a chronic problem in the area studied, and since protection costs in vaca-

tion home areas far exceed those in commercial forests, consideration of this may well affect such decisions. On the other hand, an area identified as a focus of bark beetle populations was determined to be unproductive from an economic point of view. The ends of pest management and land use would both be met if such areas were removed from timber production, which is under constant threat from insect damage, and converted to other uses such as vacation homes, grazing meadows, or recreational areas if suitably located.

The second basic principle of integrated control—"consider the ecosystem"—is of particular importance in the forest environment. The forest ecosystem as implied above is much more diverse than most agricultural ecosystems. Public ownership of and public concern for the forests far exceeds that of any agroecosystem. Our values are many and diverse, and the pest manager must be cognizant of these and include them in his recommendations.

The conventional approach to methods of control is oriented toward procedures or classes of procedure (chemical control, biological control, etc.) and to date, never set forth in an integrated system. None of the classifications of forest insect control differentiate clearly between the ramifications of a course of action and the underlying ecological theory to be served. We are sadly deficient in our understanding of the forest ecosystem, but this lack is being rectified. It seems to me that the tremendous economic growth of forestry in the past has blinded us to the fact that prior to our exploitation of the forests, forest pest problems were much less. In many of those areas that are still relatively undisturbed, problems are usually minimal. Why? It is apparent that the great majority of phytophagous insects never reach outbreak levels, and their numbers fluctuate far below the capacity of food plants to support them. Whatever theory of population regulation you ascribe to, the fact remains that the majority of our pests are man-made. It seems to me that the forests, because of their inherent species diversity (both floral and faunal) and the relatively long time over which they develop, lend themselves to the ecological approach to pest regulation and, conversely, are more susceptible to upset by a

strictly unilateral approach. We should have learned earlier from the agricultural entomologists that rarely, if ever, will single factor treatment, such as the use of parasites, predators, diseases, or an insecticide, achieve true regulation of insect populations.

Forest entomologists have, to a considerable degree, been guilty of parochialism in their approach to the problem. They have sought explanation of the eruption in entomological terms rather than ecological. On the other hand, forest entomologists have been responsible for major advances in ecological theory. However, now more than ever, it is essential that we approach each problem insect from a truly ecological viewpoint. The evidence is accumulating that outbreaks of forest insects are symptomatic of ecological disturbances in the forest ecosystems. We now have examples of insect problems occurring as a result of air pollution (*Sinclair 1969*), root diseases (*Stark and Cobb 1969*), possibly excess organic debris, site effects (*Fauss and Pierie 1969*; *Bess et al. 1949*), and probably infection by nematodes (*Ruehle 1969*) as well as the many well-documented causes (*Graham 1963; Graham and Knight, 1965*).

Yet these problems, many known for a long time, have been much less the object of study than the application of insecticides. To effect forest pest management we must investigate the true cause of insect population fluctuations and determine ways of rectifying the underlying problem. This may not be completely feasible, and regulation may be necessary. Regulation may also be necessary while attempting to determine the cause and rectify it, and the ecological approach to population regulation—integrated control—should be our goal. The pest manager should be dedicated to consider all potential techniques relevant to the particular problem, while remaining obedient to practical realities. We are obsessed when faced with an apparent abundance of insects that we *must do* something. Perhaps doing nothing might be the right decision.

We should be aware that many of our problems have their parallel in forest pathology, and the pest manager should not restrict himself. To illustrate this I have selected a few statements from books and papers in forest pathology and forest en-

tomology. I will not identify them or elaborate on them. The message should be obvious.

X	Y
Trees growing on good sites . . . are more vigorous than those on poor sites.	Vigorous trees survived when growing on favorable sites whereas less vigorous trees in same localities did not.
Trees growing under optimum stocking conditions according to age and size are more vigorous than those that are overmature.	The destruction may be reduced by regulation of forest density.
Trees from sapling age to physiological maturity are more vigorous than those that are overmature.	The importance of loss and the irreversible effects of damage increase with the age of the problem.
Uninjured trees are more vigorous than those that have had to withstand injurious influence.	Scarring of trees during logging increases incidence of the problem.

I have tried to convey the concept that, in our task of preventing damage to the forest ecosystem (whatever our value system), we should avoid the trap of merely adopting a new procedural philosophy, i.e., integrated control as a set of techniques. Rather, either individually or in cooperation with others of our persuasion and the resource manager, we look at the entire ecosystem from the viewpoint of resource management in the broadest sense.

Conclusions

Pest management, implied in the use of the human-oriented word pest, deals with the real world. Many of us have a tend-

ency to turn away from a real and immediate problem and approach it from so fundamental a level that we never get back to the problem in time to join in the solution of it.

On the other hand, we tend to think of population oscillation as being made to happen, and we seek that factor that caused it. We ignore the possibility that events happen because some antecedent event, by not happening, failed to prevent that particular oscillation. This may require extremely fundamental work.

This pest manager is an individual who has the ability to consider all variables simultaneously, is sensitive to feedback from tentative calculations, application results, and environmental or social reaction, whatever the source, is capable of assessing strategies for the deployment of time and resources, and is able to perceive the relevance of one fact to another or of hypothesis to fact (*Caws 1969*).

Also, the pest manager should bring together all elements of protection and should be subject to dictates of the forest resource involved. The forest manager should bring together all the potential uses and benefits of the area in question. Man is an animal with ingrained territorial instincts, so we tend to view the forest from our particular territory; for example, lumber producing, fishing area, a place for privacy, etc. Many forests are capable of being almost all things to all people and should be so viewed. The final set of values decided upon for any particular forest or region has a profound influence on pest management decisions.

Forest pest management can be viewed in three stages (*Geier and Clark 1960*).

1. Treatments should no longer be applied blindly according to type procedures inherited from the past or other disciplines, but should be made to conform objectively with the forest ecosystem, local circumstances, and the future.
2. A working knowledge of the natural numerical regulation of noxious species and particularly the identification of existing limiting density factors must be acquired. Regulation of an insect population should be viewed as an exercise in population dynamics.

3. Suppression of intolerable population levels (whatever the criterion) is the ultimate consequence of comprehensive husbandry based on sound ecological fact and theory. The integrated control concept is the embodiment of this philosophy.

Although great creative effort will be necessary, stage 3 should prove to be less costly, invoke less social and ecological repercussions, and be of more lasting benefit than the continued use of present-day methods, which ignore the ecological realities of pest regulation.

Last, I would like to quote the Society of American Foresters policy statement concerning forest protection. Although more honored in the breach than in observance, the philosophy of pest management is contained there:

> Protection commensurate with the values protected is essential to the management of all forest land resources. The Society advocates coordinated, intensive efforts to reduce and prevent forest losses from fire, insects, diseases, animals and other causes. Cooperation among all protection organizations and forest landowners will best achieve the objectives. Prevention is the ideal form of protection and is furthered through strong information and education programs. Public and private forest owners and the general public share the responsibility and benefits of adequate forest protection. The Society endorses programs of integrated protection involving judicious uses of ecological, biological, chemical and mechanical control."

Let us take heed!

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Management of YOUNG AND INTERMEDIATE STANDS of Upland Hardwoods

by Samuel F. Gingrich

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Management of YOUNG AND INTERMEDIATE STANDS of Upland Hardwoods

This paper is based on a talk presented at the Symposium on Southern Appalachian Hardwoods, held at Asheville, North Carolina, on 22 September 1970.

AFTER MORE than 20 years of USDA Forest Service research on the growth and yield of hardwoods in the Central States, we can now confidently make recommendations for the management and culture of upland hardwood stands that are predominantly oak. In this paper I will deal with the first 50 years of stand development under one logical thinning policy.

Our Experiment Station is conducting 11 stand-density studies in upland hardwoods, in 4 states and with more than 200 plots. The oldest studies were established in 1949. We have growth records for more than 800 measurement periods involving nearly 35,000 trees. Many of our plots have been thinned twice. The stand age of our plots ranges from 9 to 90 years. We have one major study with a single-tree design that consists of 3,500 trees, in which single-tree growth factors, such as localized density and other factors affecting tree growth, are being studied.

Our volume tables have been constructed from measurements of felled trees or from measurements of standing trees with a Barr and Stroud dendrometer. Our measurements, which total in the hundreds of thousands, can be analyzed by the latest data-processing systems. We have developed growth models and are now in the process of analyzing and publishing our results. This paper is the first report.

Growth rates and yields given in this paper are compatible with the silvicultural prescriptions and residual densities given in the *Timber Management Guide for Upland Central Hardwoods* (*4*), published in 1962, and in *Even-Aged Silviculture for Upland Central Hardwoods* (*5*), published in 1968 (USDA Agriculture

Handbook 355). With data in this paper, future yields can be predicted for stands that are thinned according to the stand characteristics and prescriptions outlined in the two guides.

GROWTH AND DEVELOPMENT OF UNTHINNED UPLAND HARDWOOD STANDS

One way of evaluating the effects of thinning is to compare the growth and yield of a thinned stand with the growth and yield of an unthinned or normal stand. The first 10 to 15 years of stand development in upland hardwoods are a dynamic period. During this "brushy" stage there are as many as 10,000 woody stems per acre, in a wide variety of commercial species and brush. This is the period of stand development when skeptics doubt whether a new forest will ever become a reality.

When the new stand is between 15 and 20 years old, certain predictable patterns can be identified. Most of the brushy species have died or are relegated to a subdominant position in the stand. The new forest has clearly emerged, and the stand has some measurable characteristics, although it is still variable in terms of species composition and spacing.

At 20 years of age the basal area per acre will range from 55 to 70 square feet, depending on the quality of the site. The total number of trees will range from about 1,400 to 2,500, most of which are commercial or at least timber trees. The larger trees on the better sites will be about 7 inches in diameter.

The normal development of these stands during the next 60 years is shown in table 1. On all sites, without thinning — that is, simply following the development of normal stands — about 90 percent of the trees present at age 20 will die during the next 60 years (table 14, in appendix). Mean annual growth culminates between age 50 and 70 years for all units of measurement. Individual tree growth is slow; and the dominant trees on site 55, at age 80, will average about 12 inches in diameter, whereas dominant trees on site 75 at age 80 will average about 18 inches in diameter.

Table 1.—*Yields per acre for upland oak; no thinning*

Age (years)	Basal area	Trees	Average tree diameter[1]	Yields		
	Square feet	*No.*	*Inches*	*Cubic feet*	*Cords*	*Board feet*
			SITE INDEX 55			
20	55	2,500	2.0	60	0.6	—
30	75	1,260	3.3	583	5.3	—
40	87	790	4.5	1,320	12.1	—
50	97	480	6.1	2,150	19.7	400
60	104	357	7.3	2,520	22.9	900
70	108	295	8.2	2,730	24.4	2,800
80	112	242	9.2	2,880	25.6	5,400
			SITE INDEX 65			
20	59	1,880	2.4	178	1.6	—
30	81	930	4.0	1,200	10.6	—
40	96	505	5.9	1,840	18.2	440
50	105	342	7.5	2,800	26.9	2,150
60	111	262	8.8	3,300	30.8	5,160
70	115	215	9.9	3,700	33.3	7,200
80	117	187	10.7	3,950	35.6	8,200
			SITE INDEX 75			
20	70	1,425	3.0	694	6.4	—
30	89	680	4.9	1,670	16.7	—
40	101	400	6.8	2,440	23.7	1,380
50	110	279	8.5	3,315	30.1	4,100
60	114	222	9.7	4,140	37.7	9,288
70	117	187	10.7	4,760	43.0	11,200
80	120	166	11.5	5,160	46.5	12,500

[1]The diameter of the tree of average basal area.

THINNING UPLAND HARDWOODS

When stands of this make-up are thinned, several things occur. Thinnings made from below result in an increase in the average tree diameter of the residual stand. This happened in all our plots, and also in other stands that we have examined. Also, the range of diameters is reduced, which means that both large and small trees are removed in the thinning.

However, generally speaking, the first and second thinnings in hardwood stands would have to be characterized as thinning from below. And there are some good reasons for this. In even-

aged stands the larger trees, being the same age as the smaller trees, have grown at a faster rate and therefore have a higher vigor rating. Except for an occasional wolf tree, the larger trees are the best quality trees in the stand and are usually the preferred species for the site.

THE THINNING SCHEDULE

For simplicity, only one thinning schedule will be considered. I have used a uniform thinning interval of 10 years on each of three site classes. Residual stocking after each thinning is near the minimum for full utilization of the site with minor adjustments that depend on the stand age at the time of the first thinning (table 2). Species composition will not be considered as a separate variable in this paper.

The site classes used are oak site indexes 55 (range 50 to 60), 65 (60 to 70), and 75 (70 to 80). Yields will be expressed in three units — total cubic-foot volume, cord volume, and board-foot volume. Volume tables and their merchantability standards are listed in table 15, in the appendix. Cubic-foot and cord volumes include all trees 4.6 inches in diameter and larger, and board-foot volumes include trees 10.6 inches in diameter and larger.

I have calculated yields based generally on thinning to a residual stocking of 60 percent or approximately B-level (*2*),

Table 2.—*Thinning policy for upland hardwood stands, showing stocking percent after each thinning. Thinning interval: 10 years.*

Stand age at first thinning (years)	Residual stocking percent after —					
	First thinning	Second thinning	Third thinning	Fourth thinning	Fifth thinning	Sixth thinning
10	50	60	60	60	60	60
20	60	60	60	60	60	60
30	70	60	60	60	60	60
40	70	60	60	60	60	60
50	70	60	60	60	60	60
60	70	65	60	60	60	60

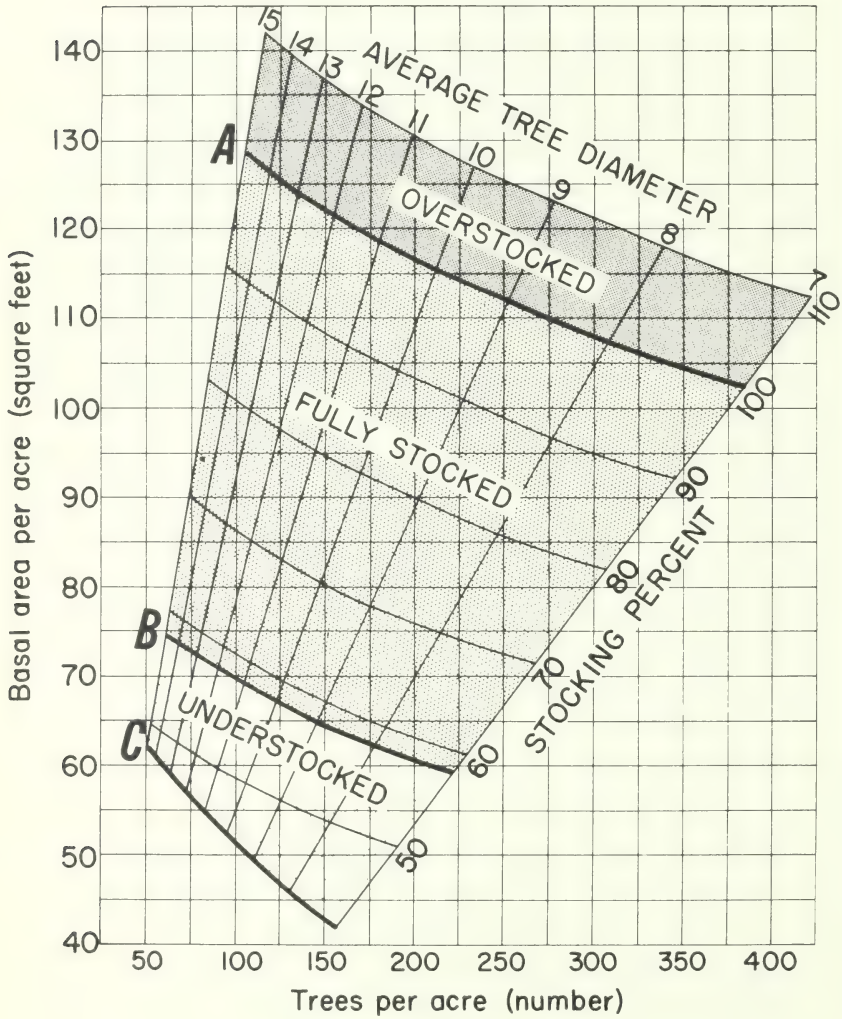
but there are several exceptions (fig. 1). For stands at age 10, I used a residual stocking of 50 percent. This was found to be the best at this age in terms of stand development (*1*). Stands of this age increase rapidly in stocking after thinning, and by age 20 they are near maximum stocking. For first thinnings in previously unthinned stands of 30 years and older, I used a residual stocking of 70 percent after the first thinning and 60 percent stocking after subsequent thinnings. Stands 60 years and older are gradually reduced to 60 percent stocking by the third thinning to reduce the possibility of epicormic branching.

Our research and practical field experience in using the *Timber Management Guide* has shown that most unmanaged hardwood stands do not have the recommended minimum stocking in desirable trees. This, of course, depends on the definition of a desirable tree; but even when tree-class standards are permissive, the minimum stocking in desirable trees is generally below the recommended residual level.

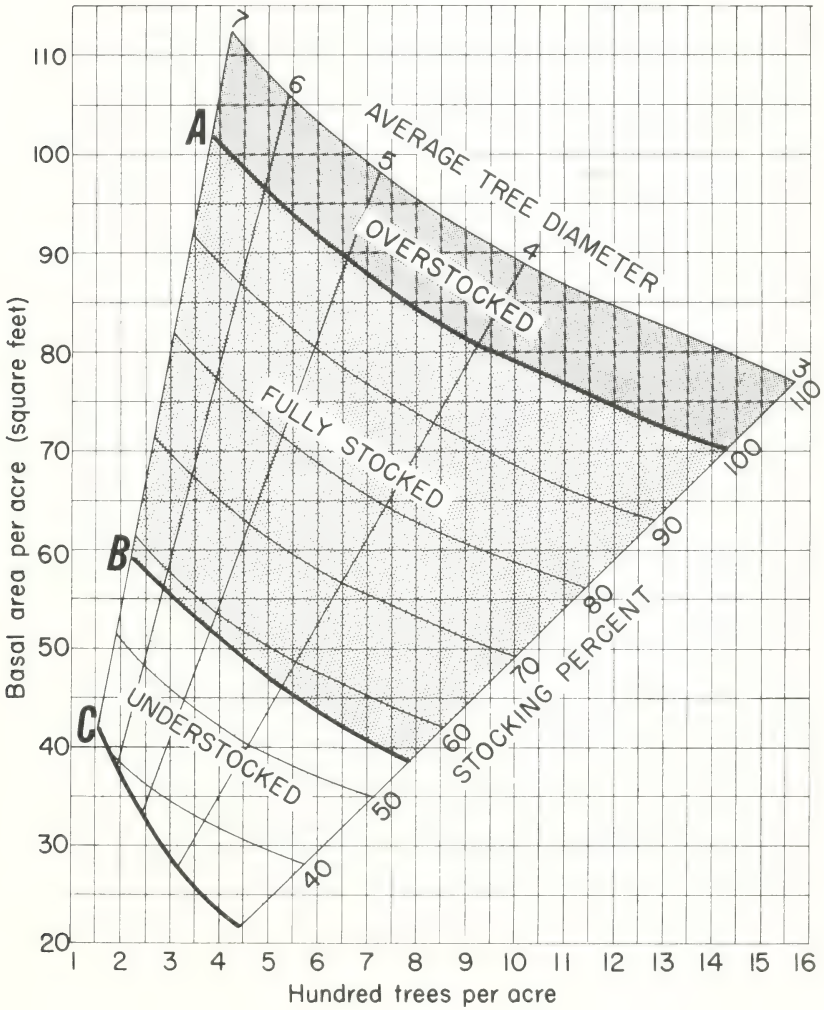
This usually means that one thinning will not put the stand in the best condition for growth. Some of the residual trees will be of low quality or of unwanted species, and spacing problems cannot always be adjusted.

There is some doubt about the value of a single thinning if subsequent thinnings are not planned. Though the intermediate yields from a single thinning may be beneficial from a management standpoint, the stand will eventually grow back to a highly stocked condition and will develop much like a normal unthinned stand, with slightly larger tree diameters.

Figure 1.—Relation of basal area, number of trees, and average tree diameter to stocking percent for upland central hardwoods. For average tree diameters 7 to 15, use the chart at left; for diameters 3 to 7, use the chart at right. (Average tree diameter is the diameter of the tree of average basal area.)



On both charts the area between curves A and B indicates the range of stocking where trees can fully utilize the site. Curve C shows the lower limit of stocking necessary to reach the B level in 10 years on average sites.



One of our studies involves a planned series of thinnings at 10-year intervals, starting at different points in the life of an even-aged upland hardwood stand.

The general stand characteristics and cumulative yields for three sites and six different stand ages for a 50-year management period and a 10-year thinning interval are shown in tables 3 to 8. The implications and utility of these types of data are very broad and cannot be discussed fully here. A few cases will serve as examples.

The possibilities for growing different amounts of timber within the range of conditions given are great. At one extreme, a recently regenerated area on site 55, if left alone for 50 years, will produce a stand of about 480 trees, averaging 6 inches in diameter. The physical yields would be 2,150 cubic feet, or 19.7 standard cords or 400 board feet per acre (table 7). At the other extreme is a 10-year-old stand on site 75 that is thinned every 10 years until age 60. This stand will have an average diameter over 15 inches and will produce 6,360 cubic feet, or 56.7 standard cords or 18,840 board feet per acre (table 3) — about three times as much cubic and cord volume as the unmanaged site 55 stand would produce.

The younger the stand age when thinning is begun, the greater the yield increase for the same management period of 50 years, except in terms of board-foot yields (table 9). For example, on site 75, stands that are first thinned at age 10 will produce more cubic-foot volume during the next 50 years than will stands that are thinned at any other age. The same is true in terms of cord yields. However, in terms of board-foot yields on sites 65 and 75, stands first thinned at age 30 or 40 will produce more yield in the next 50 years than stands that are first thinned before age 30 or after age 40. On the other hand, stands that are thinned at age 10 on site 75 will have a cumulative yield of 18,840 board feet at age 60 or a mean annual growth of 314 board feet, whereas stands first thinned at age 30 on site 75 will have a cumulative yield of 23,040 board feet at age 80 but a mean annual growth of 288 board feet.

Table 3.—*Yields per acre for upland oak. First thinning at age 10.*

Age (years)	Residual stand					Cut stand				Cumulative total yields (*cut stand plus residual stand*)		
	Basal area	Average tree diameter	Yield			Basal area	Yield					
	Square feet	*Inches*	*Cubic feet*	*Cords*	*Board feet*	*Square feet*	*Cubic feet*	*Cords*	*Board feet*	*Cubic feet*	*Cords*	*Board feet*
						SITE INDEX 55						
10	20	1.9	—	—	—	—	—	—	—	—	—	—
20	48	4.1	515	5.0	—	7	25	—	—	540	5.0	—
30	58	5.9	1,190	9.9	240	20	345	4.2	—	1,560	14.1	240
40	64	8.0	1,640	15.0	1,560	19	350	3.6	160	2,360	22.8	1,720
50	71	10.6	1,990	18.3	3,800	16	415	4.4	590	3,125	30.5	4,550
60	75	13.0	2,280	20.7	6,540	16	485	4.9	1,050	3,900	37.8	8,340
						SITE INDEX 65						
10	23	2.1	—	—	—	—	—	—	—	—	—	—
20	51	4.5	775	6.8	—	8	125	1.2	—	900	8.0	—
30	59	6.4	1,445	13.1	540	25	370	3.8	—	1,940	18.1	540
40	66	8.6	1,920	18.0	2,280	21	465	3.8	280	2,880	26.8	2,560
50	72	11.0	2,340	21.8	5,250	19	575	5.2	970	3,875	35.8	6,500
60	76	13.7	2,655	24.3	8,940	18	670	5.8	1,810	4,860	44.1	12,000
						SITE INDEX 75						
10	25	2.5	—	—	—	—	—	—	—	—	—	—
20	55	5.4	1,060	9.6	—	12	200	1.6	—	1,260	11.2	—
30	62	7.4	1,920	17.5	1,380	30	520	5.2	60	2,640	24.3	1,440
40	71	10.5	2,550	23.0	4,840	22	610	5.6	500	3,880	35.4	5,400
50	75	13.2	3,025	26.8	10,300	22	745	6.8	1,540	5,100	46.0	12,400
60	78	15.5	3,360	29.7	13,200	21	925	7.8	3,540	6,360	56.7	18,840

Table 4.—*Yields per acre for upland oak. First thinning at age 20.*

Age (years)	Residual stand					Cut stand				Cumulative total yields (*cut stand plus residual stand*)		
	Basal area	Average tree diameter	Yield			Basal area	Yield					
	Square feet	*Inches*	*Cubic feet*	*Cords*	*Board feet*	*Square feet*	*Cubic feet*	*Cords*	*Board feet*	*Cubic feet*	*Cords*	*Board feet*
						SITE INDEX 55						
20	34	2.3	60	0.6	—	—	—	—	—	60	0.6	—
30	49	4.2	600	5.1	—	15	—	0.9	—	600	6.0	—
40	58	6.1	1,220	12.2	880	16	300	2.9	—	1,520	16.0	880
50	66	8.6	1,750	16.0	2,350	15	300	3.2	150	2,350	23.0	2,500
60	71	10.6	1,980	18.6	3,960	15	360	3.2	570	2,940	28.8	4,680
70	74	12.1	2,170	20.0	5,810	14	370	3.8	820	3,500	34.0	7,350
						SITE INDEX 65						
20	37	2.8	160	1.6	—	—	18	—	—	178	1.6	—
30	50	4.6	750	7.4	—	20	132	1.2	—	900	8.6	—
40	63	7.7	1,760	16.0	1,320	15	290	3.2	—	2,200	20.4	1,320
50	69	9.8	2,150	19.7	3,500	19	625	4.1	400	3,215	28.2	3,900
60	73	12.0	2,460	22.5	6,120	18	515	4.4	1,160	4,040	35.4	7,680
70	77	14.6	2,730	24.2	9,030	16	520	4.9	2,010	4,830	42.0	12,600
						SITE INDEX 75						
20	46	3.6	476	4.4	—	—	218	2.0	—	694	6.4	—
30	57	5.6	1,275	13.0	—	26	307	3.6	—	1,800	18.6	—
40	66	8.4	2,140	19.8	2,160	21	535	4.8	240	3,200	30.2	2,400
50	71	10.8	2,600	24.7	6,450	21	665	5.4	1,160	4,325	40.5	7,850
60	76	13.4	3,060	28.5	10,680	19	615	4.9	2,020	5,400	49.2	14,100
70	79	16.3	3,465	31.5	13,720	19	635	5.2	2,740	6,440	57.4	19,880

Table 5.—*Yields per acre for upland oak. First thinning at age 30.*

Age (years)	Residual stand					Cut stand				Cumulative total yields (*cut stand plus residual stand*)		
	Basal area	Average tree diameter	Yield			Basal area	Yield					
	Square feet	*Inches*	*Cubic feet*	*Cords*	*Board feet*	*Square feet*	*Cubic feet*	*Cords*	*Board feet*	*Cubic feet*	*Cords*	*Board feet*
						SITE INDEX 55						
30	58	4.3	528	4.8	—	17	55	0.5	—	583	5.3	—
40	55	5.7	1,120	9.4	200	27	265	3.1	—	1,440	13.0	200
50	62	7.8	1,600	14.2	1,500	15	330	3.4	—	2,250	21.2	1,500
60	67	10.2	1,950	17.4	3,000	15	310	3.2	360	2,910	27.6	3,360
70	72	11.7	2,135	19.6	5,040	12	335	3.1	550	3,430	32.9	5,950
80	75	13.0	2,280	20.6	8,000	12	345	3.7	1,010	3,920	37.6	9,920
						SITE INDEX 65						
30	62	4.9	1,120	9.6	—	20	80	1.0	—	1,200	10.6	—
40	60	6.6	1,520	13.6	640	29	400	3.8	—	2,000	18.4	640
50	67	9.0	2,000	18.5	2,450	18	470	4.2	—	2,950	27.5	2,450
60	72	11.2	2,370	21.5	4,620	17	430	3.9	600	3,750	34.5	5,220
70	76	13.7	2,660	23.8	8,320	16	440	3.9	1,510	4,480	40.6	10,430
80	78	16.1	2,880	24.8	10,900	16	460	4.0	2,510	5,160	45.6	15,520
						SITE INDEX 75						
30	66	5.5	1,450	14.0	—	23	220	2.7	—	1,670	16.7	—
40	62	7.1	1,840	17.0	1,400	34	600	5.5	—	2,660	25.2	1,400
50	68	9.7	2,400	22.8	4,200	20	555	5.0	650	3,775	36.0	4,850
60	73	12.4	2,880	26.7	7,980	19	515	4.8	1,450	4,770	44.7	10,080
70	77	15.2	3,325	29.8	13,020	17	490	4.4	2,100	5,705	52.2	17,220
80	80	17.7	3,760	31.6	15,440	16	500	4.8	3,400	6,640	58.8	23,040

Table 6.—*Yields per acre for upland oak. First thinning at age 40.*

Age (years)	Residual stand					Cut stand				Cumulative total yields (*cut stand plus residual stand*)		
	Basal area	Average tree diameter	Yield			Basal area	Yield					
	Square feet	*Inches*	*Cubic feet*	*Cords*	*Board feet*	*Square feet*	*Cubic feet*	*Cords*	*Board feet*	*Cubic feet*	*Cords*	*Board feet*
						SITE INDEX 55						
40	63	5.0	1,140	10.5	—	24	180	1.6	—	1,320	12.1	—
50	62	7.4	1,538	13.0	900	23	282	3.4	—	2,000	18.0	900
60	67	9.1	1,830	15.6	2,430	15	288	3.1	270	2,580	23.7	2,700
70	72	11.0	2,065	18.6	4,445	12	300	2.7	465	3,115	29.4	5,180
80	74	12.7	2,240	21.6	6,880	12	350	2.8	865	3,640	35.2	8,480
90	76	13.8	2,430	24.8	9,180	9	355	3.0	1,100	4,185	41.4	11,880
						SITE INDEX 65						
40	69	6.5	1,600	15.9	440	27	240	2.3	—	1,840	18.2	440
50	66	8.5	1,910	17.7	1,800	28	410	4.0	200	2,560	24.0	2,000
60	70	10.4	2,200	20.7	4,200	18	400	3.6	280	3,270	30.6	4,680
70	74	12.4	2,485	23.1	7,210	16	420	3.7	710	3,955	36.7	8,400
80	77	14.5	2,720	24.8	8,960	15	410	4.0	1,050	4,600	42.4	11,200
90	79	16.5	2,925	26.6	10,710	13	460	4.0	1,630	5,265	48.2	14,580
						SITE INDEX 75						
40	73	7.4	2,130	20.2	1,380	28	300	3.0	—	2,440	23.2	1,380
50	68	9.6	2,390	21.8	3,450	31	635	6.2	300	3,325	31.0	3,750
60	73	11.6	2,730	24.9	7,680	19	625	5.2	1,020	4,290	39.3	9,000
70	76	13.8	3,115	28.0	11,200	19	610	4.8	1,620	5,285	47.2	14,140
80	79	16.5	3,480	30.8	14,080	17	590	5.2	2,340	6,240	55.2	19,360
90	81	18.7	3,735	33.7	15,840	15	660	5.3	3,000	7,155	63.4	24,120

Table 7.—*Yields per acre for upland oak. First thinning at age 50.*

Age (years)	Residual stand					Cut stand				Cumulative total yields (*cut stand plus residual stand*)		
	Basal area	Average tree diameter	Yield			Basal area	Yield					
	Square feet	*Inches*	*Cubic feet*	*Cords*	*Board feet*	*Square feet*	*Cubic feet*	*Cords*	*Board feet*	*Cubic feet*	*Cords*	*Board feet*
						SITE INDEX 55						
50	69	6.5	1,627	14.9	400	28	523	4.8	—	2,150	19.7	400
60	66	8.4	1,710	14.7	1,350	23	317	3.9	150	2,550	23.4	1,500
70	68	9.3	1,855	15.4	3,585	15	280	3.2	165	2,975	27.3	3,900
80	71	10.5	1,960	18.0	6,160	12	280	2.1	325	3,360	32.0	6,800
90	73	11.5	2,115	20.0	8,240	10	220	2.2	620	3,735	36.2	9,500
100	74	12.7	2,250	22.8	8,900	9	230	1.5	1,240	4,100	40.5	11,400
						SITE INDEX 65						
50	75	8.0	2,130	19.6	1,850	30	670	7.3	300	2,800	26.9	2,150
60	68	9.6	2,130	19.5	4,090	29	470	4.4	210	3,270	31.2	4,600
70	70	10.4	2,240	20.6	6,160	18	400	3.7	330	3,780	36.0	7,000
80	74	12.2	2,480	22.8	8,240	14	300	2.6	520	4,320	40.8	9,600
90	77	14.8	2,745	25.2	10,305	12	275	2.7	935	4,860	45.9	12,600
100	79	17.0	3,000	28.5	10,700	10	235	1.8	1,905	5,350	51.0	14,900
						SITE INDEX 75						
50	78	9.0	2,590	24.4	3,650	32	725	5.7	450	3,315	30.1	4,100
60	72	11.3	2,700	25.2	6,300	30	655	6.8	1,050	4,080	37.7	7,800
70	75	12.8	2,965	26.8	9,200	19	475	5.2	1,100	4,820	44.5	11,800
80	77	14.1	3,180	29.0	11,500	18	425	4.8	1,500	5,460	51.5	15,600
90	79	16.5	3,620	31.4	13,000	16	420	4.6	1,900	6,320	58.5	19,000
100	81	18.4	3,880	33.0	14,450	14	500	4.9	2,750	7,080	65.0	23,200

Table 8.—*Yields per acre for upland oak. First thinning at age 60.*

Age (years)	Residual stand					Cut stand				Cumulative total yields (*cut stand plus residual stand*)		
	Basal area	Average tree diameter	Yield			Basal area	Yield					
	Square feet	*Inches*	*Cubic feet*	*Cords*	*Board feet*	*Square feet*	*Cubic feet*	*Cords*	*Board feet*	*Cubic feet*	*Cords*	*Board feet*
						SITE INDEX 55						
60	76	8.2	1,860	17.1	780	28	660	5.8	120	2,520	22.9	900
70	73	9.3	1,960	17.5	2,345	19	285	4.0	685	2,905	27.3	3,150
80	70	10.3	2,000	18.4	4,320	16	335	3.0	555	3,280	31.2	5,680
90	72	11.3	2,115	19.3	5,850	10	250	2.5	530	3,645	34.6	7,740
100	74	12.3	2,200	20.8	7,300	8	270	1.9	510	4,000	38.0	9,700
110	75	13.2	2,310	22.6	8,580	7	235	2.0	570	4,345	41.8	11,550
						SITE INDEX 65						
60	78	9.4	2,400	22.2	3,900	33	900	8.6	1,260	3,300	30.8	5,160
70	75	10.2	2,450	22.1	4,550	23	360	3.6	770	3,710	34.3	6,580
80	73	12.0	2,520	23.0	5,920	20	400	3.6	810	4,180	38.8	8,760
90	77	14.1	2,610	23.8	7,785	13	365	3.6	895	4,635	43.2	11,520
100	78	15.5	2,650	25.5	9,850	12	325	3.1	915	5,000	48.0	14,500
110	80	17.2	2,750	26.6	11,770	9	345	3.1	960	5,445	52.2	17,380
						SITE INDEX 75						
60	82	10.2	3,060	27.0	7,848	32	1,080	10.7	1,440	4,140	37.7	9,288
70	78	11.5	3,150	27.3	8,540	21	460	4.7	870	4,690	42.7	10,850
80	76	13.5	3,320	28.4	9,760	21	420	4.2	1,290	5,280	48.0	13,360
90	78	15.6	3,510	29.9	10,935	16	425	3.6	1,665	5,895	53.1	16,200
100	80	17.2	3,725	31.5	12,200	13	415	3.3	1,835	6,525	58.0	19,300
110	82	19.1	3,795	33.0	13,530	9	445	3.2	1,920	7,040	62.7	22,550

Table 9.—*A comparison of yields per acre for even-aged upland hardwoods. Management period: 50 years, Cutting interval: 10 years.*

Stand age at first thinning (years)	Site 55			Site 65			Site 75		
	Volume at beginning of period	Cumulative yields 50 years later	Increase in yield	Volume at beginning of period	Cumulative yields 50 years later	Increase in yield	Volume at beginning of period	Cumulative yields 50 years later	Increase in yield
				CUBIC FEET					
10	—	3,900	3,900	—	4,860	4,860	—	6,390	6,390
20	60	3,500	3,440	178	4,830	4,652	694	6,440	5,746
30	583	3,920	3,337	1,200	5,160	3,960	1,670	6,640	4,970
40	1,320	4,185	2,865	1,840	5,265	3,425	2,440	7,155	4,715
50	2,150	4,100	1,950	2,800	5,350	2,550	3,315	7,080	3,765
60	2,520	4,345	1,825	3,300	5,445	2,145	4,140	7,040	2,900
				CORDS					
10	—	37.8	37.8	—	44.1	44.1	—	56.7	56.7
20	0.6	34.0	33.4	1.6	42.0	40.4	6.4	57.4	51.0
30	5.3	37.6	32.3	10.6	45.6	35.0	16.7	58.8	42.1
40	12.1	41.4	29.3	18.2	48.2	30.0	23.2	63.4	40.2
50	19.7	40.5	20.8	26.9	51.0	24.1	30.1	65.0	34.9
60	22.9	41.8	18.9	30.8	52.2	21.4	37.7	62.7	25.0
				BOARD FEET					
10	—	8,340	8,340	—	12,000	12,000	—	18,840	18,840
20	—	7,350	7,350	—	12,600	12,600	—	19,880	19,880
30	—	9,920	9,920	—	15,520	15,520	—	23,040	23,040
40	—	11,880	11,880	440	14,580	14,140	1,380	24,120	22,740
50	400	11,400	11,000	2,150	14,900	12,750	4,100	23,200	19,100
60	900	11,550	10,650	5,160	17,380	12,220	9,238	22,550	13,312

Therefore, though stands thinned at age 30 on site 75 produce a greater yield increase over the 50-year period, one must consider the mean annual growth difference and the compound interest for 80 years versus 60 years. For all classes of site and units of yield, stands that are first thinned at age 50 and 60 will produce substantially less yield than stands that are thinned at an earlier age.

Two examples of how the yield information might be used in making silvicultural decisions where the objective is timber production are shown in table 10. The best option can be selected by comparing the cumulative yields during the period.

In Example 1 the objective is pulpwood management. The site is 65, the stand age 30, and there have been no previous thinnings. The problem is to select one of four options that will produce the highest cord yield in a 30- and 50-year period. In the 30-year management period the best option is to start thinning, whereas for the 50-year management period the options to start thinning or to regenerate and thin will produce similar cumulative yields during the period. In the 30-year period it would be better to leave the stand alone than to regenerate, but for the 50-year period the least desirable option is to leave the stand alone. Our analyses have shown that even when first thinnings under pulpwood management are delayed until age 30, the best rotation is less than 80 years. On good sites with early thinnings, the best pulpwood rotation, when considering economic factors, may be as low as 40 years.

In Example 2 (table 10) the objective is sawtimber production. The site is 75, the stand age is 50 years, and there have been no previous thinnings. In this situation the best silvicultural option for the next 30- or 50-year period is to start thinning. The second best option for the 50-year period is to regenerate and thin, whereas for the shorter period of 30 years the second best option is to do nothing.

The best silvicultural options for a series of stand ages, two management periods, and three site classes are shown in table 11. These data show the desirability of early thinnings for all sites where maximum timber production is the objective. In the

Table 10.—*Two examples of the use of yield information in making silvicultural decisions. Figures in parenthesis refer to the table number for data source.*

EXAMPLE 1 Situation: Objective — timber production for pulpwood. Site 65, stand age 30, no previous thinnings. Management periods — 30 and 50 years. All data in standard cords.

Silvicultural options	Present volume	Volume cut during period		Residual volume at end of period		Cumulative yields[1] during period	
		30 years	50 years	30 years	50 years	30 years	50 years
Leave alone	10.6 (1,5)	—	—	30.8 (1)	35.6 (1)	30.8	35.6
Start thinning	10.6 (1,5)	12.9 (5)	20.8 (5)	21.6 (5)	24.8 (5)	34.5	45.6
Regenerate with no thinnings	10.6 (1,5)	10.6	10.6	10.6 (1)	26.9 (1)	21.2	37.5
Regenerate with thinnings	10.6 (1,5)	15.6 (3)	24.6 (3)	13.1 (3)	21.8 (3)	28.7	46.4

EXAMPLE 2 Situation: Objective — timber production for sawtimber. Site 75, stand age 50, no previous thinnings. Management periods — 30 and 50 years. All data in board feet.

Silvicultural options	Present volume	Volume cut during period		Residual volume at end of period		Cumulative yields[1] during period	
		30 years	50 years	30 years	50 years	30 years	50 years
Leave alone	4,100 (1,7)	—	—	12,500 (1)	13,500 (*)	12,500	13,500
Start thinning	4,100 (1,7)	4,100 (7)	8,750 (7)	11,500 (7)	14,450 (7)	15,600	23,200
Regenerate with no thinnings	4,100 (1,7)	4,100	4,100	— (1)	4,100 (1)	4,100	8,200
Regenerate with thinnings	4,100 (1,7)	4,160 (1,3)	6,200 (1,3)	1,380 (3)	10,300 (3)	5,540	16,500

[1]Volume cut during period + residual volume at end of period.
*Extrapolated.

Table 11.—*Best silvicultural options[1] for previously unthinned stands by stand age and site, based on predicted yields in cords and board feet. Options are: (1) leave stand alone, (2) start thinning, (3) regenerate without future thinnings, and (4) regenerate with thinnings.*

Stand age (years)	Site 55		Site 65		Site 75	
	Cords	Board feet	Cords	Board feet	Cords	Board feet
	PERIOD OF MANAGEMENT: 20 YEARS					
10	2	2	2	2	2	2
20	2	2	2	2	2	2
30	2	2	2,1	2,1	2	2
40	2,1	2	1,2,4	1,2	2,1	1,2
50	2	2	2,4,1	1,2	2,1,4	2,1
60	2	2,1	2,4	2,1	4,2,1	2,1
	PERIOD OF MANAGEMENT: 40 YEARS					
10	2	2	2	2	2	2
20	2	2	2	2	2	2
30	2	2	2,4	2	2,4	2
40	2,4	2	4,2	2	4,2	2
50	4	2	4	2	4	2
60	4	2	4	2	4	2

[1]Where two or more options are listed the physical yields are about equal.

40-year management period the best option for board-foot production is to start thinning on all sites. When pulpwood production is the objective the best option for stands 40 years and older is to regenerate and thin. However, for the shorter 20-year management period there are generally two or three options that will produce similar yields, particularly on sites 65 and 75 for stands 30 years and older. Factors other than physical yields may have to be considered in making a decision. However, when a 10-year management period is used in stands that are 30 years and older and never have been thinned, the best option, especially for pulpwood yields, is often to leave stand alone.

In the foregoing examples of silvicultural decisions based on physical yield data, economic factors have been ignored. However, except for this, the results are logical recommendations for upland hardwood stands where the same thinning policy and silvicultural principles are applied.

The thinning policy used here was selected for the convenience of making yield comparisons, and because many management plans are made for a 10-year period. The theoretically ideal thinning interval is one based on stand development. Thinnings should be made when there is a need for one as expressed in individual tree growth rate, mortality, and overall productivity. In table 12, the same residual densities shown in table 2 are used, but the thinning interval is determined by the time required for the thinned stand to reach 80 percent stocking. This policy produces a variable thinning interval. At 80 percent stocking, diameter growth and net volume growth are reduced and tree mortality starts to increase.

Both the uniform and variable thinning intervals offer some advantages. The uniform interval is administratively easier to use and will result in lower mortality, larger tree diameters, and shorter rotations than the variable thinning interval. The same arguments could be used for a 5-year thinning interval; but the point will be reached where the volume and competition removed is so small that the thinning is not very effective. On the other hand, the longer periods associated with the variable thinning interval will produce higher volumes per thinning. The important point to consider is that the thinning interval for a 20-year-old stand on site 75 should be shorter than the thinning interval for a 60-year-old stand on site 55. Each stand could be thinned at uniform intervals, but the intervals would not be the same.

Perhaps the most important factor to consider when managing for maximum timber production is the stand age when thinning begins. The yield increase in cubic feet and cords when thinnings are begun at age 10 is more than 50 percent greater than the yields when thinning is begun at age 60 (table 13). Board-foot comparisons cannot be made during this 50-year period because many of the trees have not reached the minimum size (11 inches) in stands that are first thinned at 30 years or later. When thinnings are begun at 40 years or later the total yields in cubic feet and cords are about equal to the normal development of unthinned stands. But the lower densities in the thinned stands cause an increase in the diameter growth of residual trees; con-

Table 12.—*Variable thinning interval, in years, under a thinning policy based on the change in stocking after thinning. All stands thinned when stocking attains 80 percent. Residual stocking is shown in table 2.*

Stand age at time of first thinning (years)	Site 55			Site 65			Site 75		
	Second thinning	Third thinning	Fourth thinning	Second thinning	Third thinning	Fourth thinning	Second thinning	Third thinning	Fourth thinning
10	10	11	12	8	10	12	7	8	10
20	10	14	16	8	12	14	7	10	12
30	12	16	18	10	13	16	8	12	15
40	12	18	22	10	14	18	8	14	17
50	13	20	—	12	15	—	10	15	—
60	15	22	—	13	17	—	10	16	—

Table 13.—*A comparison of yields per acre at age 60 when thinning is begun at different ages (Source: tables 3 to 8). Thinning interval—10 years.*

Yields at age 60	Age of stand at time of first thinning (years)					
	10	20	30	40	50	60
			SITE 55			
Cubic feet	3,900	2,940	2,910	2,580	2,550	2,520
Cords	37.8	28.8	27.6	23.7	23.4	22.9
Board feet	8,340	4,680	3,360	2,700	1,500	900
			SITE 65			
Cubic feet	4,860	4,040	3,750	3,270	3,270	3,300
Cords	44.1	35.4	34.5	30.6	31.2	30.8
Board Feet	12,000	7,680	5,220	4,680	4,600 (7,000)*	5,160 (6,580)*
			SITE 75			
Cubic feet	6,360	5,400	4,770	4,290	4,080	4,140
Cords	56.7	49.2	44.7	39.3	37.7	37.7
Board feet	18,840	14,100	10,080	9,000	7,800 (11,800)*	9,288 (10,850)*

*Board-foot yields at age 70 (see tables 7 and 8).

sequently there is an increase in board-foot yields, especially by age 70 (see footnote, table 13).

These data clearly indicate the potential for reducing the rotation age for upland hardwood stands under a planned thinning schedule. When thinning is begun at age 10 or 20 and is followed by periodic thinnings at 10- to 15-year intervals, the time required to grow a tree of a given diameter can be reduced by nearly 50 percent. Added to this is higher tree quality from the application of good silviculture.

SUMMARY

Three major silvicultural implications for upland hardwoods are supported by both biological and quantitative factors.

First, whether by intuition or otherwise, foresters generally thin hardwoods from below. There is a good biological basis for this. Small trees in the subdominant class that have endured long periods of high competition are not good candidates for release

by thinning. The dominant stand contains the high-vigor trees, the best quality stems, and often the preferred species for the site.

Second, a single thinning has very little effect on the final yield of a forest stand. But a one-thinning policy will produce the greatest return in terms of physical yields if it is done at an early age. A single thinning produces very small yields regardless of when it is made. In young stands the material removed is too small to utilize. In older stands the first thinning will remove defective and low-quality trees, and merchantable yields will be low. Also, first thinnings in older high-density hardwood stands do not always produce the expected growth response. Because such stands contain low-vigor trees, dense clumps, and mixed species, the first thinning may actually result in a net growth deficit (*3*). On the other hand, the accrued benefits from a thinning schedule at 10- to 15-year intervals will produce high volume returns.

Third, the earlier a stand is thinned the greater the accumulated yields over a similar management period. When precommercial thinnings are not feasible, the latest effective thinning age for pulpwood production is between 30 and 40 years, and for sawtimber production between 50 and 60 years. If thinning is not started by this age, it may be better to leave the stand alone, or to regenerate the stand, especially if it is in poor condition.

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Table 14.—*Mortality rates for upland hardwoods. Percentages indicate the proportion of trees in each diameter class that will survive the next 10-year period. For stands that are 100 ± 10% stocked.*

D.b.h. (inches)	Stand age, years					
	20	30	40	50	60	70
1	18	10	—	—	—	—
2	42	20	10	—	—	—
3	77	30	25	10	5	—
4	93	57	48	35	32	28
5	97	84	67	60	55	50
6	100	99	90	80	77	72
7	—	100	95	85	82	78
8	—	—	98	90	87	83
9	—	—	100	95	92	87
10	—	—	—	98	96	92
11	—	—	—	100	98	95
12	—	—	—	—	100	99
13	—	—	—	—	—	100

Table 15.—*Volume tables for upland hardwoods, by site classes.*

D.b.h. (inches)	Site 55				Site 65				Site 75			
	Average total height	Cubic foot volume[1]	Cord volume[2]	Board-foot volume[3]	Average total height	Cubic foot volume[1]	Cord volume[2]	Board-foot volume[3]	Average total height	Cubic foot volume[1]	Cord volume[2]	Board-foot volume[3]
5	34	2.72	0.025	—	41	3.15	0.029	—	45	3.40	0.031	—
6	41	4.28	.039	—	47	4.81	.044	—	52	5.26	.048	—
7	46	6.21	.057	—	52	6.94	.063	—	57	7.55	.069	—
8	51	8.73	.080	—	57	9.68	.088	—	63	10.6	.097	—
9	55	11.7	.107	—	62	13.1	.120	—	68	14.3	.131	—
10	50	15.3	.140	27	66	17.0	.155	36	73	18.8	.171	44
11	62	19.3	.176	46	69	21.4	.195	56	78	24.1	.220	69
12	64	22.9	.215	66	71	26.1	.238	78	82	30.0	.274	96
13	66	28.4	.259	88	73	31.3	.286	102	86	36.8	.336	128
14	67	33.3	.304	111	75	37.2	.340	130	89	44.0	.402	161
15	69	39.3	.359	139	77	43.7	.399	160	93	52.7	.481	202
16	70	45.2	.413	167	79	51.0	.465	194	95	61.2	.559	241
17	71	51.7	.472	197	81	58.9	.538	231	97	70.4	.643	284
18	72	58.7	.536	230	83	67.6	.617	271	99	80.5	.735	331
19	73	66.2	.605	265	85	77.0	.703	315	101	91.3	.835	382
20	74	74.3	.679	303	87	87.3	.797	363	102	102.2	.937	433
21	75	83.0	—	343	88	97.2	—	410	103	113.7	—	486
22	76	92.2	—	386	90	109.1	—	465	105	127.1	—	549
23	77	102.0	—	432	91	120.5	—	518	106	140.2	—	610
24	78	112.5	—	481	92	132.6	—	574	107	154.1	—	675

[1]Total cubic-foot volume of entire stem, including bark, tip, stump, but no branches. Cubic volume = $0.60 + 0.00249D^2H$

[2]Standard cords to a 4-inch top inside bark, excluding bark and branches. Cord volume = $0.00532 + 0.02275D^2H/1000$

[3]Board-foot volume, International ¼-inch rule, to an 8.5-inch top, outside bark. Board-foot volume = $41.046 + 0.01161D^2H$

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A second look at the HEAVY HALF of the Camping Market

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by Wilbur F. LaPage
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A second look at the HEAVY HALF of the Camping Market

A 1968 survey of campers revealed that one-half of the campers did more than three-fourths of all the reported camping. Campers in this heavy half of the camping market were found to differ significantly from light-half campers in their camping motivations, past experience, and investments in camping equipment *(LaPage 1969)*.

However, the 1968 survey identified heavy-half campers on the basis of a single year's (1967) participation and did not determine whether heavy-half campers consistently camped more than the average year after year. To better understand the heavy half of the camping market, we have examined the camping participation patterns of 565 campers for a period of 4 years.

In 1964 the Northeastern Forest Experiment Station began a long-term panel study of camper behavior *(LaPage and Ragain 1970)*. Panel members were selected randomly at four public

Table 1.—*Camping participation reported by the camper panel*

Year	Median camping days	Reported camping days	Percent of total by heavy half
	Days	*Days*	*Pct.*
1964	20	12,425	73
1965	18	11,866	80
1966	16	11,311	83
1967	15	11,144	85

campgrounds and four private campgrounds in New England. From 1965 to 1969 each panel member provided an annual record of his camping and other leisure-time activities and expenditures.

By annually splitting the sample of 565 campers at the median number of days camped, we determined that, in the first year, the heavy half accounted for 73 percent of the total reported camping days, and in the second, third, and fourth years the heavy half did more than 80 percent of all reported camping (table 1).

CAMPING VOLUME AND TREND

In the 1968 survey, the campers were asked to recall their volume of camping for each year since 1964. It was noted that heavy-half campers tended to increase their camping from 1964 to 1967, while light campers showed a slight decrease on the average. Our panel data reinforce both of these trend findings and show a much sharper decline for the light-half campers (table 2).

The wide differences in average participation for light-half campers are probably due to major differences in the design of the two studies. Not all panel members were active campers at the conclusion of the trend study, whereas all respondents in the 1968 survey were currently active in the camping market. Recall bias in the earlier study may be significant, as many campers probably tend to round off their figures to 7, 14, or 21 days when thinking about participation 2 or 3 years in the past.

Table 2.—*Trends in mean camping frequencies of heavy and light campers, from two independent surveys*

Year	Average days camped			
	Light half		Heavy half	
	1968 study	Panel survey	1968 study	Panel survey
1964	13	12	26	33
1965	14	8	28	34
1966	12	7	30	34
1967	12	6	34	35

Because the heavy-half of the camping market promises to be an important focus for informational and promotional campaigns by campground managers, we wanted to know how consistent a heavy-half camper is. That is, how many campers were never in the heavy half? And how many were in the heavy half for 1, 2, 3, or all 4 yours of the panel study?

Of the 565-member panel, 151 were never in the heavy half, and these campers accounted for only 9 percent of the total

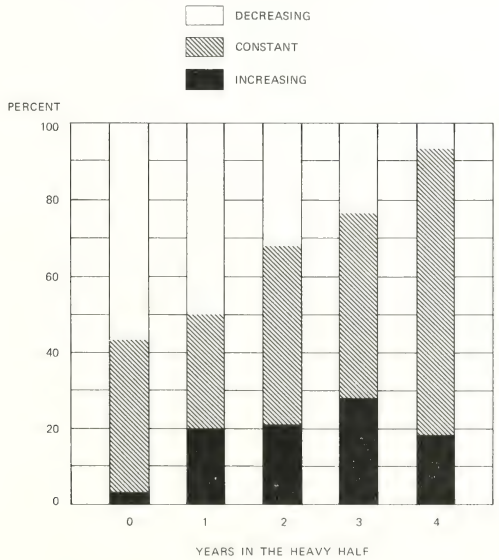

Figure 1.—The trend of camping activity according to number of years in the heavy half of the camping market.

Table 3.—*Consistency of camper representation in the heavy half.*

Number of years in the heavy-half	Study years	No. campers	Percent of 4-year reported camping
0	Total	151	9
1	1	36	
	2	23	
	3	23	
	4	21	
	Total	103	11
2	1 + 2	18	
	1 + 3	10	
	1 + 4	12	
	2 + 3	8	
	2 + 4	15	
	3 + 4	18	
	Total	81	12
3	1 + 2 + 3	23	
	1 + 2 + 4	11	
	1 + 3 + 4	15	
	2 + 3 + 4	27	
	Total	76	16
4	1 + 2 + 3 + 4	154	52
		565	100

camping; while 154 were in the heavy half all 4 years, and they accounted for 52 percent of the total camping (table 3).

After the campers had submitted questionnaires for 4 consecutive years, each camper's annual participation data were analyzed to determine whether his average camping revealed an increasing or decreasing trend. The proportion of campers who showed a decreasing trend was strongly and inversely related to the number of years in the heavy half (fig. 1). Among consistently light campers, 57 percent had decreasing trends in camping participation, as opposed to only 6 percent of those campers who were consistently in the heavy half *(LaPage and Ragain 1970).*

CHARACTERISTICS OF HEAVY-HALF CAMPERS

Our panel findings support the conclusions of earlier research that the heavy camper tends to have a larger investment in camping equipment and is therefore a potentially more mobile camper. Purchases of camping equipment over the 4-year period increased the investment gap between heavy and light campers both in total number of items acquired and in the number of expensive items purchased (table 4).

Because heavy campers had more expensive camping equipment initially, and subsequently purchased more mobile camping equipment, the heavy half had a substantially larger investment in camping equipment. The 1968 survey revealed that 68 percent of the heavy half had more than $500 invested in camping equipment as opposed to 26-percent of the light half. Our camper panel revealed a direct relationship between years in the heavy half and initial equipment investments of more than $500:

Years in the heavy half since 1964:	*Percent having more than $500 in camping equipment in 1964:*
0	11
1	30
2	36
3	50
4	59

Heavy campers may also be more socially involved in their camping. The incidence of membership in camping clubs, an apparent preference for private campgrounds, and a social attitude toward camping all increased with the number of years campers were in the heavy half (table 5).

Numerous recent studies and much popular literature point to the fact that camping can be predominantly a social experience for many people. In fact, panel members who tended to see camping in the more classical role of a physical "return to nature" were less likely to be consistent members of the heavy half, and were more likely to decrease their camping participation. However, those who perceived camping to be many things, both social and physical, were more likely to have been in the heavy half for at least one of the 4 years.

Table 4.—*Initial equipment and subsequent purchases of camping equipment by panel members, according to years in the heavy half*

Item	Years in the heavy half				
	0	1	2	3	4
Tents:					
Initial equipment (percent)	73	55	63	46	32
Purchases (number)	48	31	17	6	27
Recreation vehicles:					
Initial equipment (percent)	22	39	36	50	60
Purchases (number)	15	30	29	35	53
Tents and vehicles:					
Purchases (number)	—	—	8	11	21

Table 5.—*Some indicators of a social orientation to camping, by years in the heavy half*

Years in heavy half	Initially members of camping clubs	Express agreement with social definition of camping	Have an apparent preference for private campgrounds
	Percent	*Percent*	*Percent*
0	7	30	39
1	18	41	48
2	24	43	51
3	29	42	61
4	38	56	58

Along with a high level of involvement in camping, heavy-half campers were also more active in other forms of outdoor recreation participation (table 6). Consistently light campers averaged an additional 36 outdoor recreational events per year, while the consistently heavy camper averaged 52 events over and above his camping. Correlations between the annual volume of camping and annual participation in other forms of outdoor recreation, for 565 campers, produced coefficients that were all positive, ranging from 0.130 (camping in 1964 versus other outdoor activities in 1967) to 0.318 (camping in 1968 versus other outdoor

activities in 1968). This suggests that campers do not commonly substitute participation in camping for participation in other outdoor activities *(LaPage and Ragain 1970).*

The uniformity of average annual participation in outdoor recreation, by each of the 5 camping market segments shown in table 6, fails to reflect the widespread belief that per-capita participation is increasing.

Differences in camping style are also apparent between heavy and light campers. Based on response to the question: "Do you usually do your camping at 2 or 3 carefully selected campgrounds, or do you usually try to go to a different campground on each trip?", campers were classified as having either a repetitive or an

Table 6.—*The average number of non-camping outdoor recreational events *(and their standard deviations) each year by campers in four heavy-half categories*

Years in the heavy-half	Mean events per year ± s.d.			
	1964	1965	1966	1967
0	36 ± 27	36 ± 33	37 ± 37	34 ± 31
1	38 ± 27	37 ± 27	39 ± 30	39 ± 38
2	45 ± 52	49 ± 55	42 ± 56	37 ± 44
3	45 ± 40	43 ± 33	47 ± 45	39 ± 30
4	52 ± 39	53 ± 41	52 ± 41	53 ± 36

*Non-camping outdoor recreational events were predominantly swimming, hiking, fishing, boating, hunting, and skiing.

exploratory camping style. The two styles of camping were almost evenly represented among panel members who were recruited at the four public campgrounds, but nearly three out of four campers from the private campgrounds reported a repetitive style. Consistently heavy campers were twice as likely to have a repetitive style rather than an exploratory style of camping. The consistently light campers who had an exploratory style of camping were more than four times as likely to have been recruited at a public campground.

SIGNIFICANCE OF THE HEAVY-HALF CAMPER

If the heavy half of the camping market is to be a useful concept for campground management and promotion, two questions must be answered:

- Is membership in the heavy half simply a reflection of some other more useful concept such as a life-cycle effect, which controls entry into and exit from the heavy half?
- Who are the heavy-half campers, what do we know about them, and how can they be effectively reached?

Several findings of our camper panel research suggest that different stages of a camping life-cycle have little effect on camping volume. For example, the reduction in average annual camping by light campers, accompanied by an increase on the part of heavy campers, is at odds with the life-cycle idea of a light-camping stage developing into heavier stages. Trends in annual camping show only a weak relationship with life-cycle expressed as camper age:

Years in heavy half:	0	1	2	3	4
Percent over 45 years old:	27	27	20	29	40

Also, the distribution of past years of camping experience for each heavy-half category (table 7) reveals no direct relationship between years in the heavy half and years of camping. Many new

Table 7.—*The percentage of campers in each of three past experience categories, by number of years in the heavy half*

Years in the heavy half	Years of camping experience		
	5 or less	6 to 8	9 or more
	Percent	*Percent*	*Percent*
0	20	30	50
1	16	32	52
2	10	34	56
3	16	37	47
4	5	33	62

campers move into the heavy half during their first 5 years of camping, while many long-time campers have never been in the heavy half.

The identity of heavy-half campers, in useful marketing terms, continues to be elusive. However, the findings from this panel study suggest an important inconsistency about the heavy half: their frequent combination of expensive camping equipment having a high potential for mobility, combined with a social orientation to camping and a repetitive style of camping that results in little actual mobility. Both a repetitive style of camping and heavy camping were much more common among panel members recruited at private campgrounds. Sixty-five percent of these campers had a repetitive style, and 32 percent were consistently in the heavy half, as opposed to 45 percent and 25 percent respectively of the campers recruited at public campgrounds. These differences in camping style and frequency are reflected in the trend toward season-long campsite rentals at a great many private campgrounds. (Visits of more than 2 weeks in length are not allowed at most campgrounds managed by public agencies.) For many heavy campers, the attraction of recreational vehicles may be less in their mobility than in their comfort and convenience in a semipermanent location.

The reasons why some campers camp much more than others do are probably as many and as varied as the reasons for camping itself. Clearly no one simple explanation will account for all the individual reasons. However, our increasing knowledge of heavy-half campers emphasizes their potential importance to campground marketing.

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the relative importance of
FACTORS THAT DETERMINE LOG-HAULING COSTS

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the relative importance of FACTORS THAT DETERMINE LOG-HAULING COSTS

HAULING COSTS are a major expense to lumbermen, but little is known about which factors affect hauling costs the most. A recent Forest Service study of hauling costs on 34 logging operations sheds light on which factors of cost are important and which might require less attention. These results should help lumbermen adopt a cost accounting procedure and help them with management decisions regarding roundwood transport.

The underlying reason that factors of hauling costs have been only vaguely identified is a lack of sound cost accounting. However, this deficiency is not peculiar to the wood industry, rather to all trucking operations *(4)*.

Accurate cost information requires elaborate records which are time-consuming and costly to keep. But perhaps recording all hauling cost components is unnecessary. Possibly some items should receive close attention in a cost accounting scheme, and others may need less emphasis or could be ignored. This study points out the relative importance of the various factors of log-hauling costs.

THE STUDY

Data were collected from 34 logging operations that used gasoline powered tandem-axle trucks in West Virginia during the summer of 1968. We tried to gather the following information from each trucking situation:

- Truck specification—cost, age, make, fuel required, anticipated life, and trade-in value.
- Hours of operation—per day, per week, and per year.
- Tire data—size, cost, and life.
- Repairs—kind and cost.
- Oil, lubrication, and preventive maintenance—frequency and cost.
- Operator's wage.
- Cost of insurance.

Table 1.—*Economic data from the sample*

Factors	Values
Purchase price of truck ..... dollars	13,221.00
Salvage value ..... dollars	1,514.00
Interest rate ..... percent	12.00*
Property damage and liability insurance .... $/year	193.00
License and other fees ..... $/year	1,000.00**
Operator's hourly wage ..... $/hour	1.89
Overtime rate	1.00*[1]
Social Security ..... percent	3.90**
Unemployment compensation ..... percent	5.00**
Industrial insurance ..... percent	6.05**
Administration ..... percent	20.00*
Fuel—gasoline ..... $/gallon	.34*
Oil ..... $/quart	.75*
Lubrication and preventive maintenance.. $/lube job	15.00*
Minor repair costs ..... $/year	25.00
Major repair costs ..... $/year	218.00
Tires ..... $/tire	142.00
Tubes ..... $/tube	17.00

[1] The regular-time hourly wage is multiplied by the overtime rate to obtain the overtime hourly wage. Hence, an overtime rate of 1.00 indicates no bonus is added to overtime hours.

* This information did not come directly from the sample. It was assumed for purposes of completing the analysis.

** Obtained from State (West Virginia) and Federal regulations.

- Cost of license and other annual fees.
- Gross vehicle weight.
- Fuel consumption.
- Travel times between landing and mill—by road surface type, both loaded and empty.
- Loading and unloading time.
- Delay time.
- Volume carried (board feet).

Table 2.—*Physical data from the sample*

Factor	Values
Distance on two-lane paved roads ..... miles	21
Distance on one-lane paved roads ..... miles	4
Distance on one-lane gravel roads ..... miles	3
Distance on woods roads ..... miles	1
Time on two-lane paved portion—empty ..... minutes	34
Time on one-lane paved portion—empty ..... minutes	10
Time on one-lane gravel portion—empty ..... minutes	13
Time on woods road portion—empty ..... minutes	14
Time on two-lane paved portion—loaded ... minutes	42
Time on one-lane paved portion—loaded ... minutes	12
Time on one-lane gravel portion—loaded ... minutes	16
Time on woods road portion—loaded ..... minutes	20
Time required for loading ..... minutes	32
Delay time ..... minutes	45
Time required for unloading ..... minutes	9
Volume of the truckload ..... board feet	2,067
Hours worked ..... per day	9
Days worked ..... per week	5
Weeks worked ..... per year	42
Hours worked ..... per year	1,890
Expected truck life ..... years	5
Vacation time ..... weeks/year	None*
Average miles ..... per gallon	4
Number quarts ..... per oil change	12
Weeks between oil change	3
Weeks between lubrication and preventive maintenance	1
Oil added periodically ..... quarts	1*
Days between the added oil	2*
Number of tires on truck	10*
Tire life ..... miles	22,000

* This information did not come directly from the sample. It was assumed for purposes of completing the analysis.

These data were obtained from actual observations and by questioning operators on the 34 logging jobs. Reliability of the data varies with each item (for instance, data concerning truck purchase price and hourly wage are quite accurate; whereas data relating to the working period are based on less empirical evidence). However, for showing relative importance, these data should be quite satisfactory.

When summarizing the data from the sample trucking operators, we noticed a considerable range in values for some of the factors. For example, insurance premiums per truck ranged from $124 to $350 per year, and annual repair costs ranged from 0 to over $900. The data in tables 1 and 2 are averages and represent a condition that does not exist. However, our purpose is to measure the relative importance of these factors, so the average values will suffice.

COMPUTATION OF THE AVERAGE MACHINE RATE AND HAULING COSTS

The hauling cost calculations (fashioned after the methodology of Matthews *(3)* and Byrne *(2)*) are systematic procedures for computing the fixed, dependent, and operating costs on a per hour basis and the fuel cost on a per mile basis. To facilitate rapid computation and provide a medium for exploring the impact of changes in certain cost factors, a computer program was written. This program combines the cost elements in table 1 with the hauling distances, travel times, volume hauled, hours worked, and other factors in table 2 to generate the machine rate and hauling costs in the manner shown in tables 3 and 4.

SENSITIVITY ANALYSIS

The basic purpose of sensitivity analysis is to find out how the results of a model change when the data or parameters or assumptions of the model change *(1)*. For example, suppose we consider the following equation as a model: $Y=a+bX_1+cX_2$. To employ sensitivity analysis, we would first compute a value for

$Y(Y_1)$ using the equation in its present form. Then, holding everything else constant, we could increase the value of b by 25 percent and recompute our Y value. We now have two values of Y, Y_1 and Y_2, to compare. Suppose Y_2 is 10 percent greater than Y_1. Next we increase c by 25 percent and find that the new value of Y is 15 percent greater than Y_1. Thus, we can say that our model is more sensitive to changes in c than it is to changes in b. When a model is developed, we hope that the final results will not be very sensitive with respect to our assumptions. Thus, if the assumptions are not quite true, the results will not be way off *(1)*.

In our study, a set of equations and relationships (the model) was used to compute the hauling costs of roundwood from landing to mill (tables 3 and 4). The results of the computations were threefold: (1) a truck machine rate ($/hour) for the logging truck in question, (2) the cost of hauling logs per round-trip mile, and (3) the hauling cost per thousand board feet per round-trip mile.

Once the average values for a truck machine rate, cost per round-trip mile, and cost per thousand board feet per round-trip mile had been determined, we applied sensitivity analysis by repeating the computational process 41 times, increasing a different cost factor by 25 percent each time. When a given item was changed, all other factors were held constant; hence, the resulting machine rate, etc., (when compared to the average) reflects the impact of the component that was varied. For example, when the operator's hourly wage was increased by 25 percent (from $1.89 to $2.36), the machine rate increased by 9¼ percent (from $6.91/hour to $7.55/hour).

RESULTS

After all factors were tested, the relative importance of each was ascertained by calculating the impact a change in each factor had on the model. As an illustration, consider the effects of a 25 percent increase in the truck purchase price (from $13,221.00 to $16,526.25). This change produced nearly a 7 percent increase in the machine rate (from $6.91 per hour to $7.39 per hour). By

Table 3.—*Computation of the machine rate for average sample conditions*

Factors		Annual cost (1)	Hourly cost[1] (2)
Investment			
Truck purchase price	$13,221.00		
Less tires 10 tires @ $142.00/tire	$1,420.00		
10 tubes @ 17.00/tube	170.00		
Total cost for tires	1,590.00		
Net investment	$11,631.00		
Less salvage value after 5 years	1,514.00		
Amount to be depreciated	$10,117.00		
Fixed costs			
Depreciation—$10,117.00 ÷ 5 years		$2,023.40	$1.07
Interest—12% per year			
Average investment 8,538.20[2] × 0.12		1,024.56	.54
Insurance (property damage and liability)		193.00	.10
License and fees		1,000.00	.53
Dependent costs			
Driver's wage (no vacation and no overtime differential)		—	1.89
Social security 3.90% of 1.89		—	.07
Unemployment compensation 5.00% of 1.89		—	.09
Industrial insurance 6.05% of 1.89		—	.11
Administration 20.00% of 1.89		—	.38

Operating costs		
Oil		
(1) 42 weeks ÷ 3 weeks = 14 oil changes/year 14 × 12 quarts × $0.75/quart = ... 126.00		
(2) 1,890 hours/year ÷ 9 hours/day = 210 days/year 0.5 quarts/day × 210 days × $0.75/quart.. 78.75		
Total	204.75	.11
Lubrication and preventive maintenance—once per week—42 times per year—42 lube jobs @ $15.00 each = ...	630.00	.33
Minor repairs	25.00	.01
Major repairs	218.00	.12
Tires 22,000 miles/set of tires ÷ 58 miles/trip[3] = 379 trips/set of tires. 379 trips × 2.68[4] hours/trip = 1,016 hours/set of tires. 1,590 dollars/set of tires ÷ 1,016 hours/set of tires = ...	—	1.56
Total costs (truck machine rate), $/hour	—	$6.91

[1] Column (2) = Column (1) ÷ 1,890 hours/year. However, certain items were computed directly.

[2] Average investment = (Purchase price — salvage value) (expected life + 1)/[(2) (Expected life)] + salvage value; from Matthews *(3)*.

[3] The total hauling distance per trip—twice the one-way haul of 29 miles.

[4] Total travel time = time required when empty plus time required when loaded (that is, 161 minutes or 2.68 hours.)

Table 4.—*Computation of hauling cost per round-trip and per MBF per round-trip mile based on average sample conditions*

Factors		Values
Travel time empty		
Two-lane paved portion	minutes.. 34	
One-lane paved portion	minutes.. 10	
One-lane gravel portion	minutes.. 13	
Woods road portion	minutes.. 14	
Travel time loaded		
Two-lane paved portion	minutes.. 42	
One-lane paved portion	minutes.. 12	
One-lane gravel portion	minutes.. 16	
Woods road portion	minutes.. 20	
Total travel time	minutes.. 161	
Loading time	minutes.. 32	
Delay time	minutes.. 45	
Unloading time	minutes.. 9	
Total hauling time	minutes.. 247	
Total hauling time	hours	4.12
Hauling distance		
Two-lane paved portion	miles.. 21	
One-lane paved portion	miles.. 4	
One-lane gravel portion	miles.. 3	
Woods road portion	miles.. 1	
Total one-way hauling distance	miles.. 29	
Total hauling distance per trip	miles	58.00
Hauling cost per round-trip mile:		
4.12 hours/trip ÷ 58 miles/trip = .071 hours/mile		
.071 hours/mile × $6.91/hour =	dollars	0.491
Fuel costs:		
$0.34/gallon ÷ 4 miles/gallon =	dollars	.085
Total cost per round-trip mile	dollars	0.58
Hauling cost per MBF per round-trip mile:		
$0.58/round-trip mile ÷ 2.067 MBF =	dollars	0.28

comparing the effects of changes in both hourly wage and purchase price, it can be seen that wages are more important (in relative terms); they have a greater impact on the transportation cost structure—the model is more sensitive to changes in the wage rate than it is to variations in purchase price.

Hourly wages have the greatest influence on truck machine rates, followed closely by the factors that determine the yearly operating period, namely, hours per day, days per week, and weeks per year (tables 5, 6, and 7). A similar relationship holds for the cost per round-trip mile and cost per thousand board feet per round-trip mile. However, the ranking is not so pronounced.

APPLICATION AND LIMITATIONS

In applying the results to a hauling operation, the user should not interpret the values in an absolute sense. These cost data were obtained from sample averages, consequently the results indicate what is typical for the region and not what will arise in a specific situation. Also, most of the factors vary with the passing of time.

The approach to using the results is not to consider the values themselves, but rather to consider the ranking of values. This portrays the relative importance of the various items. It pinpoints the factors that should receive major emphasis in the planning of log transportation and in the firm's record-keeping. For examply, it is more important to have accurate records on purchase price, hourly wages, and hours of operation, than on repair and fuel costs. It is better to buy expensive tires for a low-priced truck than it is to purchase cheap tires for costly rigs. It is more economical to haul bigger loads at slower speeds than to exceed speed limits with 2 or 3 logs on the truck. These examples indicate some of the comparisons that can be made from tables 5, 6, and 7.

Although sensitivity analysis is a useful managerial tool, it does have limitations:

- A thorough analysis of complex problems requires a large capacity, high-speed computer.

- It does not provide information concerning the interaction of various factors. For instance, truck prices increase every year and this contributes to a rise in repair costs; hence, the true effect of an increase in truck prices is underestimated when sensitivity analysis is employed.
- Many factors having a substantial impact on the results are not directly controllable by the firm. For example, neither the interest rate, nor the cost for license fees can be manipulated to suit the trucking contractor. Thus, sensitivity analysis measures the importance of all factors, but changes may be impossible.

Table 5.—*Results of sensitivity analysis on the truck machine rate*

Factor changed	Percentage change in machine rate when factor was increased by 25%[1]
Driver's hourly wage	9.26
Purchase price of truck	6.95
Tire costs	4.49
Interest rate	2.03
License and other fees	2.03
Administration cost	1.45
Cost of lubrication and preventive maintenance	1.30
Overtime rate	1.01
Tube costs	.58
Industrial insurance	.43
Cost of oil	.43
Major repair costs	.43
Property damage and liability insurance	.43
Unemployment compensation	.43
Social Security	.29
Number of quarts per oil change	.29
Oil added between oil changes	.14
Minor repair costs	.14
Loading time	None
Delay time	None
Unloading time	None
Truckload volume	None
Fuel cost	None
Average miles per gallon	None
Days between oil additions	None
Weeks between oil change	—0.14
Time on one-lane paved portion—empty	— .29
Time on one-lane paved portion—loaded	— .43
Time on one-lane gravel portion—empty	— .43
Time on woods road portion—empty	— .43
Salvage value	— .43
Time on one-lane gravel portion—loaded	— .43
Time on woods road portion—loaded	— .58
Weeks between lubrication and preventive maintenance	— .87
Time on two-lane paved portion—empty	—1.01
Time on two-lane paved portion—loaded	—1.30
Expected truck life	—3.33
Tire life	—4.49
Weeks worked per year	—6.80
Days worked per week	—7.96
Hours worked per day	—8.10

[1] Minus signs indicate a decrease in the machine rate.

Table 6.—*Results of sensitivity analysis on the cost per round-trip mile*

Factor changed	Percentage change in $/round-trip mile when factor was increased by 25%[1]
Driver's hourly wage	6.90
Purchase price of truck	5.17
Delay time	3.45
Fuel cost	3.45
Tire costs	3.45
Loading time	1.72
Time on two-lane paved portion—empty	1.72
Time on two-lane paved portion—loaded	1.72
Interest rate	1.72
License and other fees	1.72
Time on one-lane gravel portion—loaded	None
Time on woods road portion—loaded	None
Overtime rate	None
Administration cost	None
Cost of lubrication and preventive maintenance	None
Time on one-lane paved portion—empty	None
Time on one-lane gravel portion—empty	None
Time on woods road portion—empty	None
Time on one-lane paved portion—loaded	None
Unloading time	None
Truckload volume	None
Property damage and liability insurance	None
Social security	None
Unemployment compensation	None
Industrial insurance	None
Cost of oil	None
Number of quarts per oil change	None
Oil added between oil changes	None
Minor repair costs	None
Major repair costs	None
Tube costs	None
Days between oil additions	None
Salvage value	—1.72
Weeks between oil change	—1.72
Weeks between lubrication and preventive maintenance	—1.72
Expected truck life	—3.45
Average miles per gallon	—3.45
Tire life	—5.17
Weeks worked per year	—6.90
Days worked per week	—6.90
Hours worked per day	—6.90

[1] Minus signs indicate a decrease in the cost per round-trip mile.

Table 7.—*Results of sensitivity analysis on the cost per MBF per round-trip mile*

Factor changed	Percentage change in $/MBF/round-trip mile when factor was increased by 25%[1]
Driver's hourly wage	7.14
Purchase price of truck	3.57
Delay time	3.57
Fuel cost	3.57
Tire costs	3.57
Time on two-lane paved portion—loaded	3.57
Loading time	3.57
Time on two-lane paved portion—empty	None
Interest rate	None
License and other fees	None
Time on one-lane paved portion—empty	None
Time on one-lane gravel portion—empty	None
Time on woods road portion—empty	None
Time on one-lane paved portion—loaded	None
Time on one-lane gravel portion—loaded	None
Time on woods road portion—loaded	None
Unloading time	None
Salvage value	None
Property damage and liability insurance	None
Overtime rate	None
Social security	None
Unemployment compensation	None
Industrial insurance	None
Administration cost	None
Cost of oil	None
Number of quarts per oil change	None
Weeks between oil change	None
Oil added between oil changes	None
Days between oil additions	None
Cost of lubrication and preventive maintenance	None
Minor repair costs	None
Major repair costs	None
Tube costs	None
Weeks between lubrication and preventive maintenance	None
Expected truck life	—3.57
Average miles per gallon	—3.57
Tire life	—3.57
Weeks worked per year	—7.14
Days worked per week	—7.14
Hours worked per day	—7.14
Truckload volue	—21.43

[1]Minus signs indicate a decrease in the cost per MBF per round-trip mile.

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THE FOREST SERVICE of the U. S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

by John E. Baumgras

CONFIGURATION OF APPALACHIAN LOGGING ROADS

U.S.D.A. FOREST SERVICE RESEARCH PAPER NE-198
1971

NORTHEASTERN FOREST EXPERIMENT STATION, UPPER DARBY, PA.
FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
WARREN T. DOOLITTLE DIRECTOR

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CONFIGURATION OF APPALACHIAN LOGGING ROADS

THE CONFIGURATION — the curvature and grade — of logging roads in southern Appalachia is seldom severe, according to a recent Forest Service study. To improve the efficiency of logging roads, we must first define the characteristics of these roads; and in this report we provide a quantitative description of the configuration of over 200 miles of logging roads.

This information will enable future work in equipment development and forest road design to be related to woods-road conditions as they actually exist. In addition, the configuration of today's forest truck roads can be compared to the requirements of future trucking equipment. This comparison will facilitate a critical review of present road-building practices in light of future demands upon logging roads.

Trucking logs to the sawmill often represents the largest single cost in Appalachian logging operations *(Appalachian Hardwood Manufacturers 1969)*. A disproportionate amount of this cost is incurred trucking over woods roads. A study in the Tennessee Valley *(Jiles and Lehman 1960)*, found the cost per mile to truck over logging roads to be twice the cost over gravel roads and three times the cost over paved roads. Thus, the cost of trucking logs over woods roads is a key element in the economics of Appalachian logging.

The physical characteristics of logging roads — grade, curvature, length, width, and surface conditions — are all determinants of trucking efficiency. When road characteristics become adverse to trucking, production delays increase; truck size and thus pay-

loads are limited; truck wear accelerates; and travel time increases. Each of these events either increases costs or decreases production.

The influence of logging road engineering has been documented for West Coast conditions *(Byrne, Nelson, and Googins 1960)*, but the same criteria may not apply to Appalachia.

THE STUDY

Objectives.—The prime objective of this study was to describe the configuration of logging roads constructed in southern Appalachia. Supplemental objectives were to assess the influence of three types of mountain topography upon road curvature and grade and to study the relationship between road length and its grade and profile. Logically, trucking efficiency increases as severity of grade and curvature decreases. Thus the type of terrain and length of road may influence trucking costs.

This paper does not give any data on the effects of road configuration upon trucking cost, nor does it compare road configuration with the most severe curves and grades negotiable by different truck types.

Study Area.—The study was conducted in three physiographic regions of the Appalachian system. We studied these three areas because each has distinct topographical characteristics that might influence logging road configuration (fig. 1).

Region A consists of long ridges oriented northeast-southwest with relatively flat to rolling terrain between the ridges. It has a regular drainage pattern.

Region B, defined as the unglaciated Allegheny plateau, has less distinct topography. Base elevations generally exceed 2,000 feet, and mountains rise to 4,000 feet above sea level. This highland plateau is laced with deep ravines and precipitous slopes and is spotted with rounded to sharp knobs and short ridges.

The third study area, region C, represents the exceptionally rough topography characteristic of the coal-field region in Kentucky and southern West Virginia. The steep hills and ridges have no recognizable orientation — thus the drainage pattern is very irregular. Elevations are lower than in region B, rising

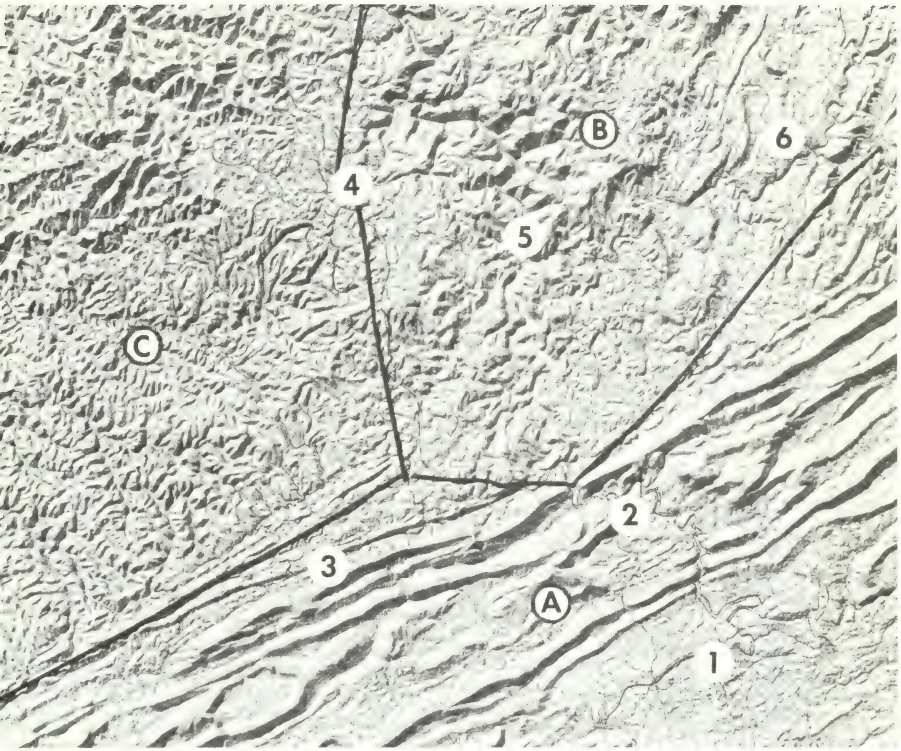


Figure 1.—Map of study area showing differences in terrain between sample regions A, B, and C. The towns indicated are (1) Radford, Va.; (2) Pearisburg, Va.; (3) Bluefield, W. Va.; (4) Beckley, W. Va.; (5) Hinton, W. Va.; and (6) Lewisburg, W. Va.

sharply from 800 feet in the coves to about 2,300 feet on the somewhat flattened ridges.

Sampling Method

To study the relationship of configuration to gross topography or road length, we stratified the roads sampled into 12 groups by using four road-length classes in each of three physiographic regions.

The logging roads surveyed were located at random from interviews with sawmill operators and loggers. We tried to locate and survey 10 roads in each sampling strata for a total of

Table 1.—*Frequency and length of sample roads used in study of logging road configuration.*

Road-length class		Number and length of roads by physiographic region					
Class	Length	(A) Ridge and valley		(B) Mountain plateau		(C) Coalfields region	
Code	*Miles*	*No.*	*Miles*	*No.*	*Miles*	*No.*	*Miles*
1	0.3 to 0.9	12	7.54	13	8.14	15	9.04
2	1.0 to 1.9	12	17.09	13	18.67	20	25.28
3	2.0 to 2.9	9	22.68	5	12.21	5	11.64
4	3.0 and longer	6	21.90	6	25.94	7	26.64
Total all classes		39	69.21	37	64.96	47	72.60

120 roads. Due to the relative scarcity of logging roads longer than 2 miles, we avoided the costly effort required to locate the prescribed number of class 3 roads (2.0 to 2.9 miles long) and class 4 roads (3 miles and longer) (table 1).

Only roads longer than 0.3 miles were sampled in this study. Furthermore, we surveyed only one road built by any given logger. These roads were located on National Forest as well as on private land.

Road Survey Technique

A new method of measuring configuration was used to provide a rapid means of adequately assessing road alignment and profile. Although less accurate than standard road survey techniques, the method described here provides accuracy adequate for assessment purposes at reduced time and cost.

Alignment Survey.—The survey consists of rolling a measuring wheel in a straight line between alignment stations and recording the cumulative distance at successive stations (fig. 2). The location of each alignment station was the intersection of the road centerline and the longest possible straight line that could be sighted down the road, keeping within the truck wheel tracks.

In figure 2, the surveyor has proceeded from station 1 to station 2 by sighting along line 1-2, stopping at 2 where the line of sight intersects the road centerline. The surveyor always meas-

ured the straight line distance between stations, thus road curvature is measured in straight line segments.

Profile Survey.—For measurements of road profile, segment length is not controlled by the line of sight, but by a prearranged difference in elevation. We selected a contour interval of 20 feet and measured the change in elevation with a sensitive surveying altimeter. We recorded the cumulative distance between successive 20-foot changes in elevation during the course of the alignment survey.

Rarely did we find that profile stations coincided with alignment stations. Usually the road segment lengths representing a 20-foot difference in elevation were much longer than the segment lengths representing curvature.

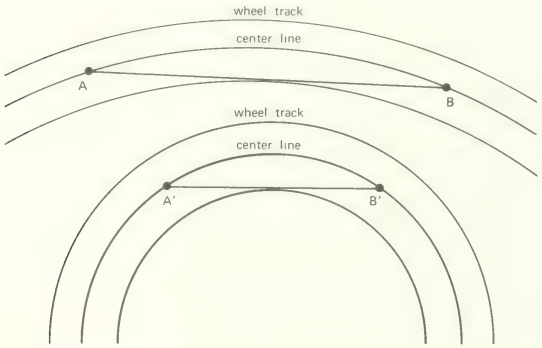
Figure 2.—Technique of measuring alignment segment lengths. Line of sight follows dotted line.

Survey Geometry

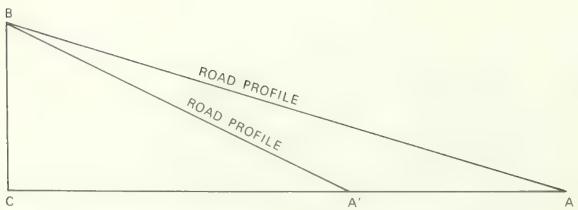
The geometry supporting this survey technique is fully explained in the appendix. Briefly, the chord length-arc radius relationship is held constant by keeping the line of sight within the wheel tracks and locating each alignment station on the road centerline. The sharper the curve, the shorter the alignment segment (fig. 3).

Profile segment lengths can be used when measuring road grade, because the segments constitute the hypotenuse of a right triangle with a constant height of 20 feet (fig. 3). Trigonometric solution of the triangle provides the base distance from which

Figure 3.—Effect of changing radius of curvature on alignment-segment lengths; and effect of changing segment length on percent of grade.



DECREASING THE RADIUS OF CURVATURE DECREASES THE ALIGNMENT – SEGMENT LENGTH FROM AB TO A'B'.

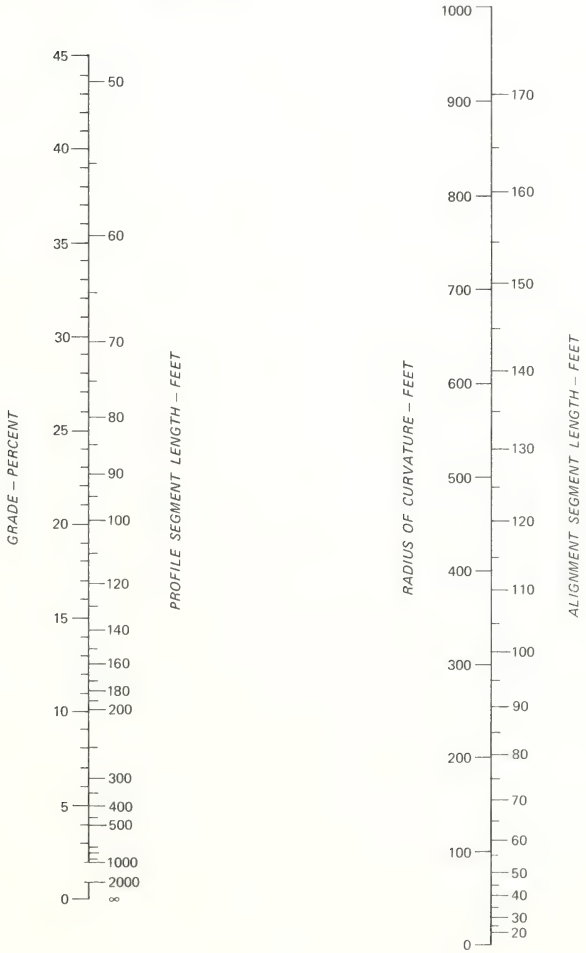


KEEPING BC CONSTANT AT 20' AND DECREASING AC TO A'C INCREASES THE GRADE OF SLOPE

percent of grade is derived. Again, segment length and severity are directly related: as profile segment length increases, steepness of grade decreases.

Alignment and profile were measured and recorded in feet of segment length. For normal engineering purposes, alignment is expressed in radius of curvature, and profile is measured in percent of grade. The charts in figure 4 convert segment length to

Figure 4.—Charts for converting segment lengths to percent grade or radius of curvature.



the standard units — radius of curvature and percent of grade. The relationships expressed by these charts are derived in the appendix.

Evaluation of Findings

The proportionate road distance associated with different levels of curvature and grade is the basis of our assessment of logging road configuration. Plots of summarized field observations as cumulative frequency distributions illustrate relative severity of curvature and grade and provide comparisons of alignment and profile between the physiographic regions and road-length classes (figs. 5 to 8).

On figures 5 to 8, cumulative frequency represents that portion of a group of roads that is equal to or less than the corresponding value on the horizontal axis. For example, in figure 5, about 25 percent of the road distance sampled in length-class 1 is in curves with a radius of 450 feet or less.

Alignment

Radius of curvature derived from alignment segments ranged from 20 to 20,000 feet. For all practical purposes, a curve with a radius exceeding 1,000 feet is negligible, almost a straight line.

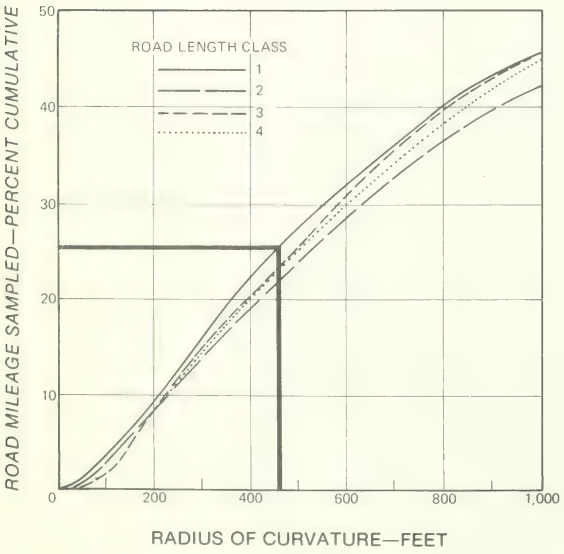


Figure 5. — Proportionate distribution of logging road mileage by radius of curvature and road length class.

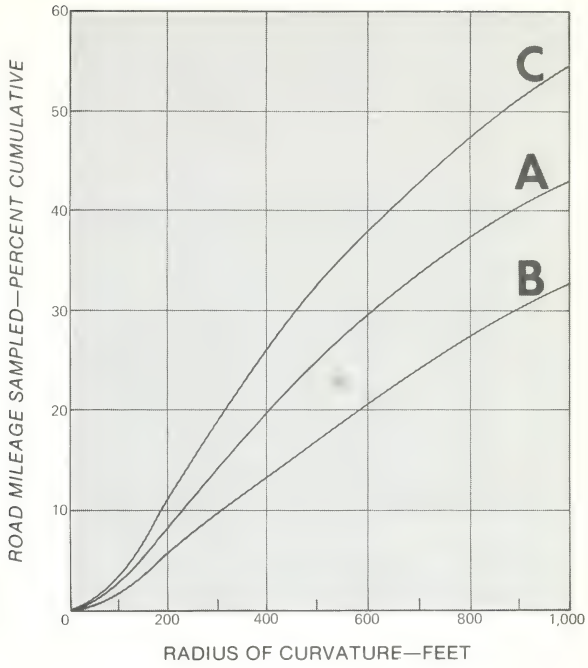


Figure 6. — Proportionate distribution of logging road mileage by radius of curvature and physiographic region.

Thus, the frequency distributions in figures 5 and 6 apply only to curves with a radius less than 1,000 feet.

Very sharp curves occurred infrequently. In fact, road curvature with a radius less than 100 feet occurred at a rate of only 160 feet per mile of road surveyed. Curves with a radius as low as 300 feet are gradual, yet 85 percent of the sampled distance exceeded this measure.

Total length of individual roads has little relation to severity of curvature (fig. 5).

As you would logically expect, physiography affected alignment (fig. 6). Roads were straightest in the mountain plateau region where 67 percent of surveyed road length had a radius of curvature exceeding 1,000 feet. The rugged and irregular topography of region C had the most severe influence upon road alignment. However, regional differences were small where alignment becomes critical; in curves with a radius less than 200 feet, the maximum difference between regions is only 6 percent.

Profile

Much of the logging road profile sampled was relatively level; a third of the mileage sampled was below 3-percent grade, and half was below 5-percent grade. Although grades as high as 25 percent were found, the extent of severe profile was very limited. On the average, only 240 feet per mile of logging road exceeded 15-percent grade.

Differences in the profile between roads of different length classes do occur (fig. 7). Short logging roads have proportionately less level grade. For example, the portion of length-class 1 and 4 in grades of 2 percent and below are 8 and 30 percent, respectively. Roads less than 1 mile long also have a higher frequency of grades exceeding 10 percent. From this data, we have concluded profile to be most severe on logging roads less than 1 mile long.

The ridges and valleys of region A and the mountain plateau topography in region B are distinctly different, yet roads in these two regions have much the same distribution of profile (fig. 8). The rugged coal field terrain had an extremely variable effect on road profile. Roads in this region had the highest proportion of

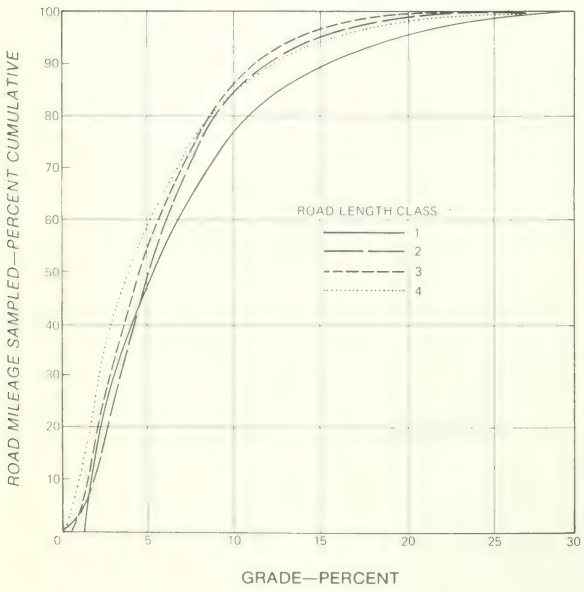


Figure 7. — Proportionate distribution of logging road mileage by percent of grade and road length class.

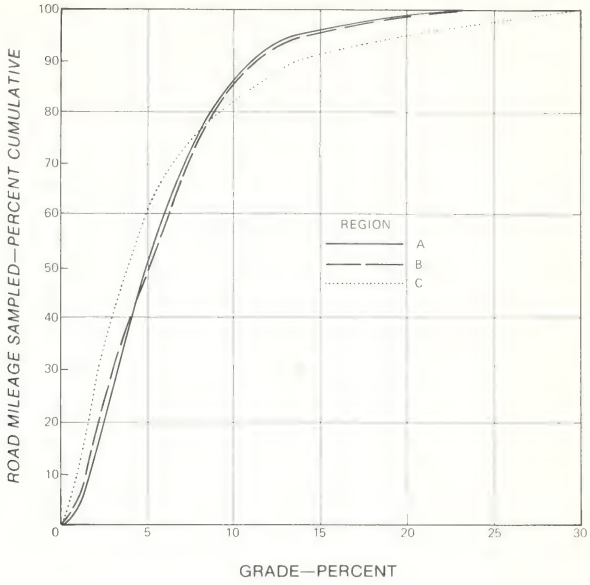


Figure 8. — Proportionate distribution of logging road mileage by percent of grade and physiographic region.

relatively level profile, yet had more grade in excess of 10 percent than did roads in regions A or B. The greatest difference in profile among the physiographic regions is in the range below 10 percent grade, which is least likely to hinder trucking.

Configuration

Thus far we have evaluated logging road alignment and profile as separate entities. However, configuration is defined as the interaction of alignment and profile. To assess configuration, we have measured this interaction as radius of curvature coincident with percent grade.

To simplify this analysis, we have reduced the infinite number of potential combinations of alignment and profile to three groups. Here are the quantitative descriptions of each group:

- *Favorable.*—Sections of a woods road where radius of curvature greater than 300 feet is mutually associated with grades less than 10 percent; in brief, neither curves nor grades are severe.

- *Moderate.*—Sections of a woods road where favorable alignment is coupled with grades steeper than 10 percent or where

favorable profile is linked to curves with radii less than 300 feet; in brief, a sharp curve coupled with a relatively flat slope or vice versa.

- *Adverse.*—Sections of woods roads where curves with radii sharper than 300 feet are associated with grades steeper than 10 percent; in brief, a combination of sharp curves and steep grades.

Illustrated in figure 9 is the percent of each road's length that meets the criteria specified for favorable, moderate, and adverse configuration. The 123 roads are arranged in order of increasing proportions of favorable configuration.

The effects of physiography and road length upon alignment and profile are reflected in configuration of individual logging roads. Roads less than 1 mile long have the poorest configuration of all roads sampled. Nine of the 10 poorest roads are class-1 roads. In addition, 9 of the 12 roads with more than 5 percent adverse configuration are also less than 1-mile long. Of the three physiographic regions, region A—ridge and valley topography—had the lowest frequency of relatively poor configuration. Only 5 roads from region A were among the 30 poorest roads; furthermore, no road in this region has more than 2-percent adverse configuration.

The following three points summarize the broad view of logging road configuration in this study:

- The shape of individual woods roads, like the rugged mountain terrain, is extremely variable. Roads range from 0- to 100-percent favorable.
- Although grades in excess of 10 percent and curves with a radius of curvature less than 200 feet frequently occur separately (described as roads of moderate configuration), they seldom occur simultaneously. Very few roads had more than 5 percent of their length in adverse configuration; the average being less than 2 percent.
- Configuration characterized by grades less than 10 percent and a radius of curvature exceeding 200 feet predominated. In fact, three out of four roads had more than 70 percent of their

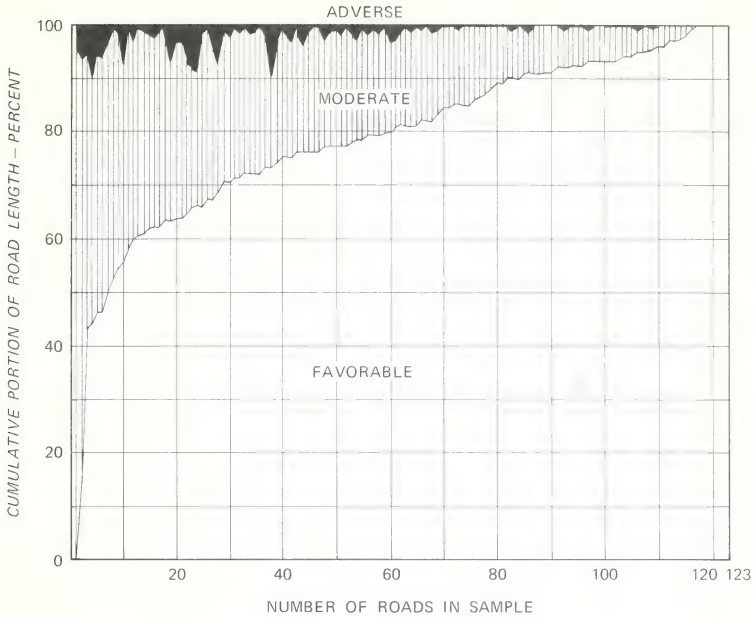


Figure 9.—Configuration of each of the 123 logging roads sampled.

length in favorable configuration; half the roads surveyed were better than 80-percent favorable.

DISCUSSION AND RECOMMENDATIONS

Because logging road configuration is the product of many factors that are seldom constant from one logging operation to another, the configuration of individual roads differs greatly. Two factors influencing configuration are road length and topography. Both influence the variation and severity of road alignment and profile. In our opinion, this influence can be attributed to road building cost. Loggers cannot afford to lengthen potentially short roads to rectify severe configuration; nor can they invest enough money in logging roads to cancel the effects of rugged terrain.

Not having a quantified relationship between logging road configuration and roundwood hauling costs, the quality of con-

figuration cannot be assessed relative to hauling cost. However, configuration has been measured in feet of segment length and assessed in terms of degrees of curvature and percent of grade. This assessment indicates configuration is predominately favorable in light of limited road building funds and rugged terrain. Since 75 percent of the total road length sampled was below 8 percent grade, and 80 percent of the curvature exceeded a radius of 300 feet; logging road configuration should not be the principal obstacle to efficient transportation of logs from landing to mill.

Although the shape of logging roads may be ruled out as the principal cause of high cost incurred when trucking over these roads, it may well be a contributing factor. Configuration of woods roads is favorable, but not optimal. The effect of sharp curves and steep grades upon hauling costs should be assessed. Then this cost can be compared to the investment required to eliminate adverse configuration. This would determine the economic feasibility of improving existing road configuration.

This appraisal suggests that researchers look elsewhere for factors that might affect roundwood transport costs. Logging road surface condition is one such factor, trucking equipment is another. It is possible that high costs are inevitable using the present trucking system, and a new concept of extracting logs is in order. Here are our specific recommendations for future research:

- Determine the influence of adverse configuration on hauling time and cost.
- Compare the costs of improving configuration with the costs of hauling where severe curves and grades have not been eliminated.
- Establish the link between road surface conditions and hauling costs.
- Compare the costs of improving woods-road surface with the benefits derived from operating on the better surface.
- Compare costs of operating the present system, trucking logs over woods roads, to that of alternate systems such as forwarding logs to surfaced roads.

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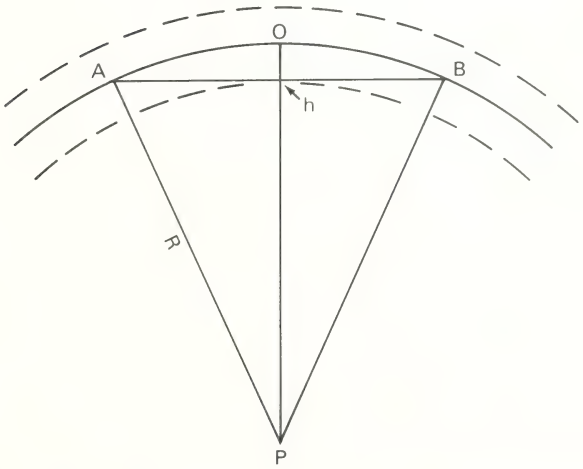
APPENDIX

Deriving Radius of Curvature from Alignment Segment Length



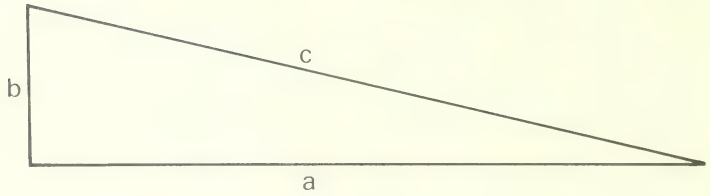
AP = OP = BP = radius of curvature, R
AB = line of sight, segment length, chord of arc AOB
AOB = arc of road center line
Oh = constant middle ordinate, 4 feet from center line to inside wheel track
hP = radius minus middle ordinate = OP — Oh

By definition $AB = 2\sqrt{R^2-hP^2}$
substituting (R—4) for hP, $AB = 2\sqrt{R^2-(R-4)^2}$
deriving R $AB = 2\sqrt{8R-16}$

$$R = \frac{AB^2}{32} + 2$$

$$\text{Radius of curvature} = \frac{(\text{segment length})^2}{32} + 2$$

Deriving Percent of Grade from Profile Segment Length



a = horizontal distance—feet

b = vertical distance, a constant 20 feet

c = profile segment length—measured distance in feet

Grade in percent is defined as $\frac{\text{vertical distance}}{\text{horizontal distance}} \times 100$

The profile survey measures the length of c, b is a constant of 20 feet. Using the Pythagorean theory, $a = \sqrt{c^2 - b^2}$. By substitution, percent

$$\text{grade} = \frac{b}{\sqrt{c^2 - b^2}} \times 100$$

$$\text{Percent grade} = \frac{20}{\sqrt{(\text{segment length})^2 - 400}} \times 100$$

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by Leland F. Hanks

Interim Hardwood TREE GRADES For Factory Lumber

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FOREST SERVICE, U. S. DEPARTMENT OF AGRICULTURE
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FOREST SERVICE INTERIM GRADES

HARDWOOD TREES have for many years been measured in such a way that tree volume could be estimated; and in recent years the prediction of tree quality by using tree grades has become of interest to owners, sellers, and buyers of timber. Several tree-grading systems have been developed, but none has been publicized and used on a widespread scale. The Forest Service recently adopted and approved interim hardwood tree grades for factory lumber. The specifications for these tree grades and the associated lumber grade volumes for yellow birch, red maple, and black oak are presented here.

BACKGROUND

There have been several attempts to develop tree grades for hardwoods (*Campbell 1951, 1959; Herrick and Jackson 1957; Hyvarinen 1968; Lucas 1969; Marden 1965; Schroeder 1964*). Most of these have involved single species. The most widely used method was developed by the USDA Forest Service at Carbondale, Illinois (*Herrick and Jackson 1957*). In this system, a tree's grade is equal to the grade of the best 10-foot section of the 16-foot butt log. Another system, used in the Northeast, involves grading each log in the standing tree. For both of these tree-grading methods, lumber grade yields for sample trees were estimated from yields of logs sawed in earlier log-grade studies (*Vaughan et al. 1966*). In other words, the same lumber grade volumes were applied to all sections of sample trees exhibiting comparable diameter and log grade. The estimated lumber grade yields were accepted as actual, and it was understood that variance estimates were not meaningful.

Tree Grades

By 1965, a large accumulation of actual lumber grade yield data from hardwood trees was available. We reviewed past tree-grade research and selected yellow birch for a test to verify whether or not the best 10-foot grading system was valid for use with actual yields.

In addition to the best 10-foot section, we planned to test the best 8- and 12-foot sections of the 16-foot butt log, the entire 16-foot butt log, and several versions of the tree-grading system employed by Forest Survey.

Our initial investigation, concerned with the best grading section, utilized data from 195 yellow birch trees. The trees had been selected and measured, and the logs were sawed in Michigan, Vermont, and West Virginia, resulting in dry board volumes and grades. The tree selectors graded the standing trees, using the system employed by Forest Survey. The full range of d.b.h. (diameter at breast height), merchantable height, and quality classes available at each sample location was represented, and all portions of the tree that qualified as local-use or better were processed into factory lumber. (A local-use class log must scale at least 8 inches d.i.b. — diameter inside bark — by 8 feet long and must be one-third sound. The diameter of knots, holes, rot, etc. cannot exceed one-half the diameter of the log at the point of occurrence).

Also, each tree's surface characteristics were recorded on paper diagrams by trained personnel representing all branches of the Forest Service. When the grades from the diagrams were compared with the grades obtained during tree selection, we found that they differed often. We credited this to differences in defect identification between the graders. We chose the grades assigned during tree selection, reasoning that they could most likely be duplicated in normal practice.

A tree was given the grade of the butt 16-foot log, except that, when a 12- or 14-foot section of the 16-foot log was better, the grade of this shorter section was used. The section was graded according to specifications contained in Hardwood Log

Grades for Standard Lumber (*Vaughan et al. 1966*). However, sound end defect and shake were not considered.

Total value per thousand board feet was obtained for each tree (1967 lumber prices). For each tree grade, these values were plotted over d.b.h. Many trees that were placed below the average contained a significant amount of scalable defect in the butt log. The 10-percent level of scalable defect was the most consistent breaking point between trees that were obviously misplaced and trees that were not. The system was modified to have a more stringent interpretation of scalable defect than originally applied.

To supplement the yellow birch data, representative samples of red maple and black oak trees were selected, and the logs were sawed (fig. 1). An analysis similar to that used on yellow birch was conducted; and, as before, the grades assigned during

Figure 1. — Location of study mills (general areas where the sample trees for the species indicated were cut).

tree selection frequently differed from the diagram grades. Once again we chose the grading system used in the field and modified it to include the more restrictive scalable defect rule.

Although the diagrams were not the basis for the final tree grades, they were used for the tests to establish the best grading section. However, the tests were not conclusive. The non-random sampling procedure precluded valid tests of the differences between the several tree-grading systems. Additional data were needed; and, because of the urgent need for tree grades, we decided to forego further tests. For the sample that was available, the plots of total value per thousand board feet over d.b.h. indicated that the tree grades presented here exhibited less within-grade variation than the other trial grading systems.

Lumber Yields

To be useful over time, tree grades should be accompanied by a predictor that is more stable than lumber prices. We developed multiple regression equations for each species and tree grade that predict dry volume by lumber grade (tables 2 to 4). D.b.h.^{2} and merchantable height functioned as independent variables for yellow birch and red maple, and d.b.h.^{2} $\times$ merchantable height was added to the model for black oak. If a model did not perform as expected, we eliminated independent variables that were not significant.

The equations were solved for the desired combinations of d.b.h. and merchantable height resulting in board-foot volume tables by tree grade and lumber grade for yellow birch, red maple, and black oak (tables 5 to 7).

The lumber grade volumes were summed for each d.b.h.-height class resulting in predicted total tree volumes. These were compared between tree grades and species and with actual total lumber volumes of the sample trees. In the few instances where the predicted volumes were obviously wrong, we corrected each lumber grade volume using hand-fitted curves through the actual data. These changes have been incorporated in the volume tables.

The practice of hand-fitting discussed above is well established, and at times faster than an extensive search for the proper mathematical model.

We have included the lumber thickness distribution for each species (tables 8 to 10). In nearly all cases, the thickness pattern represents that of sawing for best grade; that is, sawing for the thickest potential board, up to 8/4 inches, without lowering the board grade. A different pattern followed in sawing for grade would cause small differences in yield.

Mean lumber grade yields, standard errors of the residuals, and correlation coefficients are included in tables 11 to 13.

TREE GRADE SPECIFICATIONS

Grading Rules

Table 1 contains the specifications of the interim hardwood tree grades for factory lumber.

Application

The grading rules are for use on standing hardwood trees. Strict attention must be paid to the specifications. A tree's grade is determined by the grade of the butt log, the tree d.b.h., and an estimate of the scalable defect in the grading section. Useful log-grading aids are contained in the following publications:

1. *A guide to hardwood log grading (rev.).* Ostrander, M. D., and others. 1965. USDA Forest Serv. NE. Forest Exp. Sta., 50 pp., illus. NE. Forest Exp. Sta., Upper Darby, Pa.

2. *Hardwood log grades for standard lumber.* Vaughan, C. L., A. C. Wollin, K. A. McDonald, and E. H. Bulgrin. 1966. USDA Forest Serv. Res. Paper FPL-63, 52 pp., illus. Forest Prod. Lab., Madison, Wis.

3. *Grade defects in hardwood timber.* Lockard, C. R., J. A. Putnam, and R. D. Carpenter. 1963. USDA Agr. Handbook 244, 39 pp., illus.

4. *Defect indicators in sugar maple.* Marden, Richard M., and Charles L. Stayton. 1970. USDA Forest Serv. Res. Paper NC-37, 29 pp., illus. NC. Forest Exp. Sta., St. Paul, Minn.

Those seeking a discussion of how to estimate deductions for sweep and crook are referred to No. 1 above (p. 36 to 37). Because the defect is visible, the deduction for sweep or crook in the standing tree should be comparable to that for a log on the ground.

The chore of estimating interior defect is more difficult and subjective. Some insight into the art of scaling interior cull in trees may be gained from No. 1 above and from the following:

1. *Estimating defect in tree-length hardwoods.* Nyland, Ralph D. 1970. Northern Logger. 18:8.
2. *A photo guide to the patterns of discoloration and decay in living northern hardwood trees.* Shigo, Alex L., and Edwin vH. Larson. 1969. USDA Forest Serv. Res. Paper NE-127, 100 pp., illus. NE. Forest Exp. Sta., Upper Darby, Pa.
3. *Shortcuts for cruisers and scalers.* L. R. Grosenbaugh. 1952. USDA Forest Serv. S. Forest Exp. Sta. Occas. Paper 126, pp. 14-15. S. Forest Exp. Sta., New Orleans, La.

LUMBER GRADE VOLUME AND VALUE ESTIMATION

Use of the lumber grade volume tables requires the following field data for each tree:

- Species.
- Tree grade.
- D.b.h. to the nearest inch.
- Merchantable height to the nearest half-log. (Height is the distance from the top of a 1-foot stump to where local-use material ends. For forked trees, consider only the longest fork).

The predicted volumes are net volumes derived from actual mill yields and should not be adjusted for cull or overrun.

When estimating a tree's value:

1. Consult the appropriate table and record the volumes by lumber grade for the tree in question.
2. Apply current dry lumber prices to the lumber volumes to obtain lumber value per grade.
3. Sum the value of lumber in all grades to arrive at tree value.

If desirable, a lumber grade price may be weighted in proportion to the volume that a mill is producing in each lumber grade-thickness class, as in the following example (Firsts and Seconds lumber grade):

Thickness class	*Percent of volume*	*Price*
4/4	50	$360/M bd. ft.
5/4	25	$365/M bd. ft.
6/4	25	$375/M bd. ft.
	FAS weighted price =	$365/M bd. ft.

DISCUSSION

The tree grades presented in this paper have been classed as interim. Lumber grade yields for only three species are available, and these have not been field-tested on trees outside the sample trees. Successful field tests and yields for additional species are necessary to change the grades from interim to standard Forest Service grades.

Because the yields are based on actual sawed lumber volumes, these grades have an advantage over present tree grading systems.

We envision the interim grades and yields being used as is and with local adjustments based on comparison tests of predicted and actual mill-manufactured dry lumber tallies.

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Table 1. — Interim hardwood tree grades for factory lumber

Grade factor	Tree grade 1			Tree grade 2		Tree grade 3
Diameter (minimum i.b. at 17 feet) ....inches.....	13	16	20	[1]11	12	8
D.b.h. (minimum) .....inches.....	16	16	16	13	13	10
Length of grading section[2] .....feet.....	Butt 16			Butt 16		Butt 16
Clear cuttings (on the 3 best faces)[3]:						
Length (minimum) .....feet.....	7	5	3	3	3	2
Number on face (maximum)	2	2	2	2	3	Unlimited
Yield in face length (minimum)	5/6	5/6	5/6	4/6	4/6	3/6
Cull deduction, including crook and sweep but excluding shake (maximum) ....pct.....	9	9	9	[4]9	9	50

[1]Grade 2 trees can be 10 inches i.b. at top of grading section if otherwise meeting surface requirements for small grade 1.

[2]Whenever a 12- or 14-foot section of the butt 16-foot log is better than the entire log, the grade of the shorter section will become the grade of the tree. This shorter section, when used, is the basis for determining the grading factors such as diameter and cull deduction.

[3]A clear cutting is a portion of a face free of defects, extending the width of the face. A face is ¼ of the surface of the grading section as divided lengthwise.

[4]15 percent crook and sweep or 40 percent total cull deduction permitted in grade 2 if size and surface of grading section qualify as grade 1. If rot shortens the required clear cuttings to the extent of dropping the butt log to grade 2, do not drop the tree's grade to 3 if the cull deduction for rot is greater than 9 percent.

Table 2. — Regression equations for yellow birch

Dependent variable: lumber grade	Independent variables		
	Constant	D.b.h.^{2}	Merchantable height
	TREE GRADE 1		
FAS	— 81.6	+0.2508	+0.948
FAS1F	+ 4.9	+ .0627	—
Selects	+ .9	+ .0046	+ .161
No. 1C	—131.3	+ .3091	+2.169
No. 2C	— 46.0	+ .1279	+1.494
No. 3A	— 42.5	+ .0713	+1.326
No. 3B	— 5.0	+ .0373	+ .594
	TREE GRADE 2		
FAS	— 26.4	+0.0915	+0.425
FAS1F	— 11.9	+ .0534	+ .288
Selects	+ 3.7	+ .0024	+ .049
No. 1C	— 13.0	+ .1313	+ .598
No. 2C	— 41.6	+ .1138	+1.487
No. 3A	— 6.5	+ .0383	+ .836
No. 3B	— 12.6	+ .0491	+ .785
	TREE GRADE 3		
FAS	— 1.1	+0.0076	+0.015
FAS1F	— 5.1	+ .0304	+ .091
Selects	+ 1.3	+ .0023	—
No. 1C	— 35.8	+ .1921	+ .650
No. 2C	— 35.4	+ .1162	+1.638
No. 3A	— 15.1	+ .0657	+ .978
No. 3B	+ 8.1	+ .0437	+ .332

Table 3. — Regression equations for red maple

Dependent variable: lumber grade	Independent variables		
	Constant	D.b.h.^{2}	Merchantable height
	TREE GRADE 1		
FAS	−90.4	+0.2337	+1.492
FAS1F	−46.4	+ .1140	+1.167
Selects	−18.7	+ .0371	+ .453
No. 1C	−53.8	+ .2165	+ .820
No. 2A	−39.6	+ .2129	+ .590
No. 2B	+23.1	—	+ .611
No. 3A	−20.5	+ .0592	+ .464
No. 3B	−25.0	+ .0476	+ .439
	TREE GRADE 2		
FAS	−46.1	+0.1699	+0.555
FAS1F	−35.7	+ .1294	+ .662
Selects	− 4.5	+ .0204	+ .249
No. 1C	−46.6	+ .2091	+ .749
No. 2A	− 6.0	+ .0802	+1.086
No. 2B	+21.1	+ .0110	+ .677
No. 3A	− 9.6	+ .0349	+ .426
No. 3B	−19.0	+ .0840	+ .123
	TREE GRADE 3		
FAS	−13.4	+0.0416	+0.270
FAS1F	−21.5	+ .0809	+ .404
Selects	− 5.3	+ .0315	+ .132
No. 1C	−30.0	+ .1558	+ .720
No. 2A	−21.1	+ .0792	+1.195
No. 2B	+ 4.1	—	+1.320
No. 3A	− 3.4	+ .0654	+ .115
No. 3B	− 3.1	+ .0442	+ .032

Table 4. — Regression equations for black oak

Dependent variable: lumber grade	Independent variables			
	Constant	D.b.h.^{2}	Merchantable height	D.b.h.^{2} × Merchantable height
		TREE GRADE 1		
FAS	+44.8	−0.0618	−2.258	+0.006163
FAS1F	+70.9	− .0891	−2.037	+ .005013
Selects	− 5.7	+ .0296	—	—
No. 1C	−28.4	+ .1135	− .319	+ .005598
No. 2C	−16.4	+ .0354	+1.372	+ .001458
SW	− 5.3	—	+ .545	—
No. 3A	+81.3	− .1263	− .228	+ .003056
No. 3B	−27.6	− .0387	+1.572	+ .001249
		TREE GRADE 2		
FAS	−17.7	+0.0998	—	—
FAS1F	− 2.5	+ .0656	−0.438	+0.001269
Selects	−15.1	+ .0313	+ .424	− .000571
No. 1C	−84.4	+ .3001	+ .292	+ .003256
No. 2C	− 3.3	+ .0134	− .041	+ .005019
SW	−13.6	—	+ .629	—
No. 3A	+ 2.7	− .0026	+ .856	+ .001574
No. 3B	+11.2	− .0479	+ .930	+ .000673
		TREE GRADE 3		
FAS	+ 2.8	−0.0105	−0.308	+0.001659
FAS1F	−11.1	+ .0747	—	—
Selects	+ 4.0	− .0144	− .184	+ .000819
No. 1C	−35.9	+ .2870	—	—
No. 2C	−33.7	+ .1504	+1.281	− .000197
SW	−10.6	+ .0465	+ .711	− .001239
No. 3A	−35.0	+ .2101	+1.880	− .004353
No. 3B	+ 8.6	− .2269	+1.102	+ .006792

Table 5. — Lumber grade volume for yellow birch

[In board feet]

D.b.h. (inches)	FAS	FAS1F	Selects	No. 1C	No. 2C	No. 3A	No. 3B
			TREE GRADE 1, 1½ -LOGS				
16	9.6	21.0	5.9	17.0	33.8	11.5	18.8
17	17.2	23.0	6.1	20.0	33.9	12.5	20.0
18	24.7	25.2	6.3	25.0	34.6	13.7	21.3
19	31.7	27.5	6.4	32.3	36.0	15.1	22.7
20	41.5	30.0	6.6	44.4	41.0	17.8	24.2
21	51.8	32.6	6.8	57.1	46.3	20.8	25.7
22	62.5	35.2	7.0	70.4	51.8	23.8	27.3
23	73.8	38.1	7.2	84.3	57.5	27.0	29.0
24	85.6	41.0	7.4	98.8	63.5	30.4	30.7
25	97.9	44.1	7.6	113.9	69.8	33.9	32.6
26	110.7	47.3	7.9	129.7	76.3	37.5	34.5
			TREE GRADE 1, 2-LOGS				
16	15.1	21.0	7.2	20.7	40.1	21.3	23.6
17	22.5	23.0	7.4	29.1	41.2	21.8	24.8
18	30.0	25.2	7.5	38.3	43.2	23.0	26.1
19	39.3	27.5	7.7	49.7	48.0	25.7	27.5
20	49.1	30.0	7.9	61.7	53.0	28.5	28.9
21	59.3	32.6	8.1	74.4	58.2	31.4	30.5
22	70.1	35.2	8.3	87.7	63.7	34.4	32.1
23	81.4	38.1	8.5	101.6	69.5	37.6	33.7
24	93.2	41.0	8.7	116.1	75.5	41.0	35.5
25	105.5	44.1	8.9	131.3	81.7	44.5	37.3
26	118.3	47.3	9.2	147.1	88.3	48.1	39.2
27	131.6	50.6	9.4	163.4	95.0	51.9	41.2
28	145.4	54.1	9.7	180.4	102.1	55.8	43.3
29	159.7	57.6	9.9	198.1	109.4	59.9	45.4
30	174.5	61.3	10.2	216.3	116.9	64.1	47.6
			TREE GRADE 1, 2½-LOGS				
16	20.5	21.0	8.5	34.6	46.5	28.8	28.3
17	28.8	23.0	8.7	44.8	50.7	31.1	29.5
18	37.6	25.2	8.8	55.6	55.2	33.6	30.8
19	46.9	27.5	9.0	67.0	59.9	36.3	32.2
20	56.6	30.0	9.2	79.1	64.9	39.1	33.7
21	66.9	32.6	9.4	91.8	70.2	42.0	35.2
22	77.7	35.2	9.6	105.1	75.7	45.0	36.8
23	89.0	38.1	9.8	119.0	81.4	48.3	38.5
24	100.8	41.0	10.0	133.5	87.4	51.6	40.2
25	113.1	44.1	10.2	148.6	93.7	55.1	42.1
26	125.9	47.3	10.4	164.4	100.2	58.7	44.0
27	139.2	50.6	10.7	180.8	107.0	62.5	46.0
28	152.9	54.1	10.9	197.8	114.0	66.4	48.0

CONTINUED

Table 5. — Continued

D.b.h. (inches)	FAS	FAS1F	Selects	No. 1C	No. 2C	No. 3A	No.
29	167.2	57.6	11.2	215.4	121.3	70.5	50.
30	182.0	61.3	11.5	233.6	128.9	74.7	52.
			TREE GRADE 1, 3-LOGS				
16	28.1	21.0	9.8	51.9	58.5	39.4	33.
17	36.4	23.0	10.0	62.1	62.7	41.8	34.
18	45.2	25.2	10.1	73.0	67.2	44.2	35.
19	54.4	27.5	10.3	84.4	71.9	46.9	37.
20	64.2	30.0	10.5	96.5	76.9	49.7	38.
21	74.5	32.6	10.7	109.1	82.1	52.6	40.
22	85.3	35.2	10.9	122.4	87.6	55.7	41.
23	96.6	38.1	11.1	136.3	93.4	58.9	43.
24	108.4	41.0	11.3	150.9	99.4	62.2	45.
25	120.7	44.1	11.5	166.0	105.6	65.7	46.
26	133.4	47.3	11.7	181.8	112.2	69.3	48.
27	146.7	50.6	12.0	198.1	119.0	73.1	50.
28	160.5	54.1	12.2	215.1	126.0	77.0	52.
29	174.8	57.6	12.5	232.8	133.3	81.1	54.
30	189.6	61.3	12.8	251.0	140.8	85.3	57.
			TREE GRADE 2, 1-LOG				
13	0.0	1.7	4.9	18.8	1.4	13.3	8.
14	.0	3.2	5.0	22.3	4.5	14.4	9.
15	1.0	4.7	5.0	26.1	7.8	15.5	11.
16	3.8	6.4	5.1	30.2	11.3	16.7	12.
17	6.8	8.1	5.2	34.5	15.1	17.9	14.
18	10.0	10.0	5.3	39.1	19.1	19.3	15.
19	13.4	12.0	5.4	44.0	23.3	20.7	17.
20	17.0	14.1	5.4	49.1	27.7	22.2	19.
21	20.8	16.3	5.5	54.5	32.4	23.8	21.
22	24.7	18.6	5.6	60.1	37.3	25.4	23.
23	28.8	21.0	5.8	66.0	42.4	27.1	25.
24	33.1	23.5	5.9	72.2	47.7	28.9	28.
			TREE GRADE 2, 1½-LOG				
13	0.0	4.0	5.3	23.5	13.3	20.0	14.
14	1.7	5.5	5.3	27.1	16.4	21.1	15.
15	4.4	7.0	5.4	30.9	19.7	22.2	17.
16	7.2	8.7	5.5	35.0	23.2	23.4	18.
17	10.2	10.4	5.6	39.3	27.0	24.6	20.
18	13.4	12.3	5.7	43.9	31.0	26.0	22.
19	16.8	14.3	5.7	48.8	35.2	27.4	24.
20	20.4	16.4	5.8	53.9	39.6	28.9	25.
21	24.2	18.6	5.9	59.3	44.3	30.5	27.
22	28.1	20.9	6.0	64.9	49.2	32.1	30.

CONTINU

'able 5. — Continued

D.b.h. (inches)	FAS	FAS1F	Selects	No. 1C	No. 2C	No. 3A	No. 3B
23	32.2	23.3	6.1	70.8	54.3	33.8	32.2
24	36.5	25.8	6.3	77.0	59.6	35.6	34.5
			TREE GRADE 2, 2-LOGS				
13	2.7	6.3	5.7	28.3	25.2	26.7	20.8
14	5.1	7.8	5.7	31.9	28.3	27.8	22.1
15	7.8	9.3	5.8	35.7	31.6	28.9	23.6
16	10.6	11.0	5.9	39.7	35.1	30.1	25.1
17	13.6	12.7	6.0	44.1	38.9	31.3	26.7
18	16.8	14.6	6.0	48.7	42.9	32.7	28.4
19	20.2	16.6	6.1	53.5	47.1	34.1	30.2
20	23.8	18.7	6.2	58.7	51.5	35.6	32.2
21	27.6	20.9	6.3	64.0	56.2	37.1	34.2
22	31.5	23.2	6.4	69.7	61.1	38.8	36.3
23	35.6	25.6	6.5	75.6	66.2	40.5	38.5
24	39.9	28.1	6.7	81.8	71.5	42.3	40.8
			TREE GRADE 2, 2½-LOGS				
13	6.1	8.6	6.1	33.1	37.1	33.4	27.1
14	8.5	10.1	6.1	36.7	40.2	34.4	28.4
15	11.2	11.6	6.2	40.5	43.5	35.6	29.8
16	14.0	13.3	6.3	44.5	47.0	36.7	31.4
17	17.0	15.1	6.4	48.9	50.8	38.0	33.0
18	20.2	16.9	6.4	53.5	54.8	39.3	34.7
19	23.6	18.9	6.5	58.3	59.0	40.8	36.5
20	27.2	21.0	6.6	63.4	63.4	42.3	38.4
21	31.0	23.2	6.7	68.8	68.1	43.8	40.5
22	34.9	25.5	6.8	74.5	73.0	45.5	42.6
23	39.0	27.9	6.9	80.4	78.1	47.2	44.8
24	43.3	30.4	7.0	86.5	83.4	49.0	47.1
			TREE GRADE 2, 3-LOGS				
13	9.5	10.9	6.5	37.9	49.0	40.1	33.4
14	11.9	12.4	6.5	41.4	52.1	41.1	34.7
15	14.6	13.9	6.6	45.2	55.4	42.2	36.1
16	17.4	15.6	6.7	49.3	58.9	43.4	37.6
17	20.4	17.4	6.7	53.6	62.7	44.7	39.3
18	23.6	19.2	6.8	58.2	66.6	46.0	41.0
19	27.0	21.2	6.9	63.1	70.9	47.5	42.8
20	30.6	23.3	7.0	68.2	75.3	48.9	44.7
21	34.4	25.5	7.1	73.6	80.0	50.5	46.7
22	38.3	27.8	7.2	79.3	84.9	52.2	48.8
23	42.4	30.2	7.3	85.2	90.0	53.9	51.1
24	46.7	32.7	7.4	91.3	95.3	55.7	53.4

CONTINUED

Table 5. — Continued

D.b.h. (inches)	FAS	FAS1F	Selects	No. 1C	No. 2C	No. 3A	No. 3
			TREE GRADE 3, 1-LOG				
10	0.0	0.0	1.5	0.0	2.4	7.1	17.8
11	.1	.0	1.6	.0	4.9	8.5	18.7
12	.2	.7	1.6	2.3	7.5	10.0	19.7
13	.4	1.5	1.7	7.1	10.4	11.7	20.8
14	.6	2.3	1.8	12.3	13.6	13.4	22.0
15	.8	3.2	1.8	17.8	17.0	15.3	23.2
16	1.1	4.1	1.9	23.8	20.6	17.4	24.6
17	1.3	5.1	2.0	30.1	24.4	19.5	26.0
18	1.6	6.2	2.0	36.8	28.5	21.8	27.6
19	1.9	7.3	2.1	43.9	32.8	24.3	29.2
20	2.2	8.5	2.2	51.4	37.3	26.8	30.9
			TREE GRADE 3, 1½-LOGS				
10	0.0	0.1	1.5	0.0	15.5	14.9	20.4
11	.2	.8	1.6	3.0	18.0	16.3	21.4
12	.4	1.5	1.6	7.5	20.6	17.8	22.4
13	.5	2.2	1.7	12.3	23.5	19.5	23.5
14	.7	3.0	1.8	17.5	26.7	21.2	24.6
15	1.0	3.9	1.8	23.0	30.1	23.2	25.9
16	1.2	4.9	1.9	29.0	33.7	25.2	27.3
17	1.5	5.9	2.0	35.3	37.5	27.4	28.7
18	1.7	6.9	2.0	42.0	41.6	29.7	30.2
19	2.0	8.1	2.1	49.1	45.9	32.1	31.8
20	2.3	9.2	2.2	56.6	50.4	34.7	33.5
21	2.6	10.5	2.3	64.5	55.2	37.3	35.3
22	2.9	11.8	2.4	72.8	60.2	40.2	37.2
			TREE GRADE 3, 2-LOGS				
10	0.1	0.9	1.5	4.2	28.6	22.8	23.1
11	.3	1.5	1.6	8.2	31.1	24.1	24.0
12	.5	2.2	1.6	12.7	33.7	25.7	25.0
13	.7	2.9	1.7	17.5	36.7	27.3	26.1
14	.9	3.8	1.8	22.7	39.8	29.1	27.3
15	1.1	4.7	1.8	28.2	43.2	31.0	28.6
16	1.3	5.6	1.9	34.2	46.8	33.0	29.9
17	1.6	6.6	2.0	40.5	50.6	35.2	31.4
18	1.8	7.7	2.0	47.2	54.7	37.5	32.9
19	2.1	8.8	2.1	54.3	59.0	39.9	34.5
20	2.4	10.0	2.2	61.8	63.5	42.5	36.2
21	2.7	11.2	2.3	69.7	68.3	45.2	38.0
22	3.1	12.5	2.4	78.0	73.3	48.0	39.9
23	3.4	13.9	2.5	86.6	78.5	51.0	41.8
24	3.8	15.3	2.6	95.6	83.9	54.0	43.9

CONTINUEI

Table 5. — Continued

D.b.h. (inches)	FAS	FAS1F	Selects	No. 1C	No. 2C	No. 3A	No. 3B
TREE GRADE 3, 2½-LOGS							
12	0.6	2.9	1.6	17.9	46.9	33.5	27.7
13	.8	3.7	1.7	22.7	49.8	35.1	28.8
14	1.0	4.5	1.8	27.9	52.9	36.9	29.9
15	1.2	5.4	1.8	33.4	56.3	38.8	31.2
16	1.4	6.3	1.9	39.4	59.9	40.8	32.6
17	1.7	7.3	2.0	45.7	63.7	43.0	34.0
18	2.0	8.4	2.0	52.4	67.8	45.3	35.5
19	2.2	9.5	2.1	59.5	72.1	47.7	37.2
20	2.5	10.7	2.2	67.0	76.6	50.3	38.9
21	2.9	11.9	2.3	74.9	81.4	53.0	40.7
22	3.2	13.3	2.4	83.2	86.4	55.8	42.5
23	3.5	14.6	2.5	91.8	91.6	58.8	44.5
24	3.9	16.1	2.6	100.8	97.1	61.9	46.6

Table 6. — Lumber grade volume for red maple

[In board feet]

D.b.h. (inches)	FAS	FAS1F	Selects	No. 1C	No. 2A	No. 2B	No. 3A	No. 3B
TREE GRADE 1, 2-LOGS								
16	20.5	23.9	6.3	33.2	40.2	42.7	11.3	1.4
17	28.1	26.9	7.3	39.5	46.0	42.7	13.0	3.2
18	35.7	30.1	8.4	46.0	52.1	42.7	14.6	4.9
19	43.5	33.5	9.6	52.8	58.5	42.7	16.4	6.5
20	50.8	36.5	10.6	59.0	64.4	42.7	18.0	8.1
21	60.4	41.2	12.2	67.9	73.2	42.7	20.5	10.0
22	70.5	46.1	13.8	77.2	82.3	42.7	23.0	12.1
23	81.0	51.2	15.4	87.0	91.9	42.7	25.7	14.2
24	92.0	56.6	17.2	97.1	101.9	42.7	28.4	16.5
25	103.4	62.2	19.0	107.8	112.3	42.7	31.3	18.8
26	115.3	68.0	20.9	118.8	123.2	42.7	34.4	21.2
TREE GRADE 1, 2½-LOGS								
16	31.6	32.1	9.7	37.4	41.8	47.5	14.3	5.1
17	38.7	34.9	10.6	43.7	47.8	47.5	16.0	6.6
18	45.0	37.2	11.4	49.1	53.0	47.5	17.2	8.0
19	53.6	41.4	12.8	57.2	60.9	47.5	19.4	9.7
20	62.8	45.9	14.3	65.6	69.2	47.5	21.7	11.6
21	72.3	50.6	15.8	74.5	77.9	47.5	24.2	13.6
22	82.4	55.5	17.4	83.8	87.0	47.5	26.7	15.6

CONTINUED

Table 6. — Continued

D.b.h. (inches)	FAS	FAS1F	Selects	No. 1C	No. 2A	No. 2B	No. 3A	No. 3I
23	92.9	60.6	19.0	93.5	96.6	47.5	29.4	17.7
24	103.9	65.9	20.8	103.7	106.6	47.5	32.2	20.0
25	115.3	71.5	22.6	114.3	117.1	47.5	35.1	22.3
26	127.3	77.3	24.5	125.4	127.9	47.5	38.1	24.7
				TREE GRADE 1, 3-LOGS				
16	41.0	38.8	12.5	41.0	43.2	52.4	16.9	8.3
17	48.8	42.6	13.8	48.1	50.2	52.4	18.9	9.8
18	56.9	46.6	15.1	55.7	57.7	52.4	21.0	11.5
19	65.6	50.8	16.4	63.7	65.6	52.4	23.1	13.3
20	74.7	55.2	17.9	72.2	73.9	52.4	25.5	15.1
21	84.3	59.9	19.4	81.0	82.6	52.4	27.9	17.1
22	94.3	64.8	21.0	90.3	91.8	52.4	30.4	19.1
23	104.8	69.9	22.7	100.1	101.3	52.4	33.1	21.3
24	115.8	75.3	24.4	110.3	111.4	52.4	35.9	23.5
25	127.3	80.9	26.2	120.9	121.8	52.4	38.8	25.8
26	139.2	86.7	28.1	131.9	132.6	52.4	41.8	28.2
				TREE GRADE 1, 3½-LOGS				
16	53.0	48.1	16.2	47.5	47.9	57.3	20.6	11.8
17	60.7	51.9	17.4	54.7	55.0	57.3	22.6	13.3
18	68.9	55.9	18.7	62.3	62.4	57.3	24.7	15.0
19	77.5	60.1	20.1	70.3	70.3	57.3	26.9	16.8
20	86.6	64.6	21.5	78.7	78.6	57.3	29.2	18.6
21	96.2	69.2	23.0	87.6	87.3	57.3	31.6	20.6
22	106.3	74.1	24.6	96.9	96.5	57.3	34.1	22.6
23	116.8	79.3	26.3	106.6	106.1	57.3	36.8	24.8
24	127.8	84.6	28.0	116.8	116.1	57.3	39.6	27.0
25	139.2	90.2	29.9	127.4	126.5	57.3	42.5	29.3
26	151.1	96.0	31.7	138.5	137.4	57.3	45.5	31.8
				TREE GRADE 1, 4-LOGS				
16	64.9	57.5	19.8	54.1	52.7	62.2	24.4	15.3
17	72.6	61.2	21.0	61.2	59.7	62.2	26.3	16.9
18	80.8	65.2	22.3	68.8	67.1	62.2	28.4	18.5
19	89.5	69.4	23.7	76.8	75.0	62.2	30.6	20.3
20	98.6	73.9	25.1	85.3	83.3	62.2	32.9	22.1
21	108.1	78.6	26.7	94.2	92.0	62.2	35.3	24.1
22	118.2	83.5	28.2	103.5	101.2	62.2	37.8	26.1
23	128.7	88.6	29.9	113.2	110.8	62.2	40.5	28.3
24	139.7	94.0	31.7	123.4	120.8	62.2	43.3	30.5
25	151.2	99.5	33.5	134.0	131.2	62.2	46.2	32.8
26	163.1	105.4	35.4	145.0	142.1	62.2	49.2	35.3

CONTINUED

Table 6. — Continued

D.b.h. inches)	FAS	FAS1F	Selects	No. 1C	No. 2A	No. 2B	No. 3A	No. 3B
				TREE GRADE 2, 2-LOGS				
13	0.4	7.4	6.9	12.7	42.3	44.6	9.9	0.0
14	5.0	10.8	7.5	18.4	44.5	44.9	10.9	1.4
15	9.9	14.6	8.1	24.4	46.8	45.2	11.9	3.8
16	15.2	18.6	8.7	30.9	49.3	45.6	13.0	6.4
17	20.8	22.9	9.4	37.8	51.9	45.9	14.1	9.2
18	26.7	27.4	10.1	45.1	54.7	46.3	15.3	12.2
19	33.0	32.2	10.8	52.9	57.7	46.7	16.6	15.3
20	39.6	37.2	11.6	61.0	60.8	47.2	18.0	18.5
21	46.6	42.5	12.5	69.6	64.1	47.6	19.4	22.0
22	53.9	48.1	13.3	78.6	67.6	48.1	20.9	25.6
23	61.5	53.9	14.3	88.0	71.2	48.6	22.5	29.4
24	69.5	60.0	15.2	97.8	74.9	49.1	24.1	33.3
				TREE GRADE 2, 2½-LOGS				
13	4.8	12.6	8.9	18.7	51.0	50.0	13.3	0.1
14	9.4	16.1	9.5	24.3	53.2	50.3	14.3	2.4
15	14.3	19.9	10.0	30.4	55.5	50.7	15.3	4.8
16	19.6	23.9	10.7	36.9	58.0	51.0	16.4	7.4
17	25.2	28.2	11.4	43.8	60.6	51.4	17.5	10.2
18	31.1	32.7	12.1	51.1	63.4	51.7	18.7	13.1
19	37.4	37.5	12.8	58.8	66.4	52.2	20.0	16.2
20	44.1	42.5	13.6	67.0	69.5	52.6	21.4	19.5
21	51.0	47.8	14.5	75.6	72.8	53.0	22.8	23.0
22	58.3	53.4	15.3	84.6	76.3	53.5	24.3	26.6
23	66.0	59.2	16.3	94.0	79.9	54.0	25.9	30.4
24	74.0	65.3	17.2	103.8	83.6	54.5	27.5	34.3
				TREE GRADE 2, 3-LOGS				
13	9.3	17.9	10.9	24.7	59.7	55.5	16.7	1.1
14	13.8	21.4	11.5	30.3	61.8	55.8	17.7	3.4
15	18.8	25.2	12.0	36.4	64.2	56.1	18.7	5.8
16	24.0	29.2	12.7	42.9	66.7	56.4	19.8	8.4
17	29.6	33.5	13.3	49.8	69.3	56.8	20.9	11.2
18	35.6	38.0	14.1	57.1	72.1	57.2	22.2	14.1
19	41.9	42.8	14.8	64.8	75.1	57.6	23.4	17.2
20	48.5	47.8	15.6	73.0	78.2	58.0	24.8	20.5
				TREE GRADE 3, 1-LOG				
10	0.0	0.0	0.0	0.0	5.9	25.2	5.0	1.8
11	.0	.0	.6	.4	7.6	25.2	6.4	2.8
12	.0	.0	1.3	4.0	9.4	25.2	7.9	3.8
13	.0	.0	2.1	7.9	11.4	25.2	9.5	4.9
14	.0	.8	3.0	12.1	13.5	25.2	11.3	6.1
15	.3	3.2	3.9	16.6	15.8	25.2	13.2	7.4

CONTINUED

Table 6. — Continued

D.b.h. (inches)	FAS	FAS1F	Selects	No. 1C	No. 2A	No. 2B	No. 3A	No. 3B
16	1.6	5.7	4.9	21.4	18.3	25.2	15.2	8.7
17	2.9	8.3	5.9	26.5	20.9	25.2	17.3	10.2
18	4.4	11.2	7.0	32.0	23.7	25.2	19.6	11.7
19	5.9	14.2	8.2	37.8	26.6	25.2	22.0	13.4
20	7.6	17.3	9.4	43.8	29.7	25.2	24.6	15.1
				TREE GRADE 3, 1½-LOGS				
10	0.0	0.0	1.0	2.9	15.5	35.8	5.9	2.1
11	.0	.0	1.7	6.1	17.2	35.8	7.3	3.0
12	.0	.0	2.4	9.7	19.0	35.8	8.8	4.0
13	.1	1.9	3.2	13.6	21.0	35.8	10.4	5.1
14	1.2	4.1	4.0	17.8	23.1	35.8	12.2	6.3
15	2.4	6.4	5.0	22.3	25.4	35.8	14.1	7.6
16	3.7	8.9	5.9	27.2	27.9	35.8	16.1	9.0
17	5.1	11.6	7.0	32.3	30.5	35.8	18.3	10.4
18	6.6	14.4	8.1	37.8	33.2	35.8	20.5	12.0
19	8.1	17.4	9.2	43.5	36.2	35.8	23.0	13.6
20	9.7	20.6	10.5	49.6	39.3	35.8	25.5	15.3
				TREE GRADE 3, 2-LOGS				
10	0.0	0.0	2.1	8.6	25.1	46.3	6.8	2.3
11	.3	1.2	2.7	11.9	26.7	46.3	8.2	3.3
12	1.2	3.1	3.5	15.5	28.5	46.3	9.7	4.3
13	2.3	5.1	4.2	19.4	30.5	46.3	11.3	5.4
14	3.4	7.3	5.1	23.6	32.7	46.3	13.1	6.6
15	4.6	9.6	6.0	28.1	35.0	46.3	15.0	7.9
16	5.9	12.1	7.0	32.9	37.4	46.3	17.0	9.2
17	7.3	14.8	8.0	38.1	40.0	46.3	19.2	10.7
18	8.7	17.6	9.1	43.5	42.8	46.3	21.5	12.2
19	10.3	20.6	10.3	49.3	45.7	46.3	23.9	13.9
20	11.9	23.8	11.5	55.4	48.8	46.3	26.4	15.6
				TREE GRADE 3, 2½-LOGS				
12	3.4	6.3	4.5	21.2	38.1	56.9	10.6	4.5
13	4.4	8.3	5.3	25.1	40.1	56.9	12.3	5.6
14	5.6	10.5	6.2	29.3	42.2	56.9	14.0	6.8
15	6.8	12.9	7.1	33.9	44.5	56.9	15.9	8.1
16	8.0	15.4	8.0	38.7	47.0	56.9	17.9	9.5
17	9.4	18.0	9.1	43.8	49.6	56.9	20.1	11.0
18	10.9	20.9	10.2	49.3	52.4	56.9	22.4	12.5
19	12.4	23.9	11.4	55.0	55.3	56.9	24.8	14.1
20	14.0	27.0	12.6	61.1	58.4	56.9	27.4	15.9
				TREE GRADE 3, 3-LOGS				
13	6.6	11.6	6.4	30.9	49.6	67.5	13.2	5.9

CONTINUED

Table 6. — Continued

D.b.h. (inches)	FAS	FAS1F	Selects	No. 1C	No. 2A	No. 2B	No. 3A	No. 3B
14	7.7	13.7	7.2	35.1	51.8	67.5	14.9	7.1
15	8.9	16.1	8.1	39.6	54.1	67.5	16.8	8.4
16	10.2	18.6	9.1	44.4	56.5	67.5	18.9	9.8
17	11.6	21.3	10.1	49.6	59.1	67.5	21.0	11.2
18	13.0	24.1	11.2	55.0	61.9	67.5	23.3	12.8
19	14.6	27.1	12.4	60.8	64.9	67.5	25.7	14.4
20	16.2	30.3	13.6	66.9	67.9	67.5	28.3	16.1

Table 7. — Lumber grade volume for black oak

[In board feet]

D.b.h. (inches)	FAS	FAS1F	Selects	No. 1C	No. 2C	SW	No. 3A	No. 3B
TREE GRADE 1, 2-LOGS								
16	7.3	18.0	1.9	36.4	31.0	12.2	66.7	23.1
17	11.7	21.7	2.9	46.0	38.0	12.2	65.8	23.1
18	16.5	25.6	3.9	56.3	45.0	12.2	64.8	23.2
19	21.5	29.7	5.0	67.1	52.5	12.2	63.8	23.2
20	26.7	34.3	6.2	78.5	60.4	12.2	62.6	23.2
21	32.3	37.2	7.4	90.5	63.8	12.2	61.5	23.3
22	38.1	40.3	8.7	103.1	67.3	12.2	60.3	23.3
23	44.2	43.5	10.0	116.2	71.0	12.2	59.0	23.4
24	50.6	46.9	11.4	130.0	74.8	12.2	57.6	23.5
25	57.2	50.4	12.8	144.3	78.9	12.2	56.2	23.5
26	64.1	54.0	14.3	159.3	83.0	12.2	54.8	23.6
TREE GRADE 1, 2½-LOGS								
16	7.3	18.0	1.9	45.3	62.5	16.5	71.2	38.2
17	11.7	21.7	2.9	56.4	65.6	16.5	71.0	38.6
18	16.5	25.6	3.9	68.2	68.9	16.5	70.9	39.0
19	21.2	29.7	5.0	80.7	72.4	16.5	70.8	39.4
20	28.4	34.1	6.2	93.9	76.0	16.5	70.6	39.8
21	36.0	38.6	7.4	107.7	79.9	16.5	70.4	40.3
22	43.9	43.4	8.7	122.2	83.9	16.5	70.3	40.8
23	52.2	48.4	10.0	137.4	88.1	16.5	70.1	41.3
24	60.9	53.7	11.4	153.2	92.5	16.5	69.9	41.8
25	70.0	59.1	12.8	169.8	97.1	16.5	69.7	42.3
26	79.4	64.8	14.3	187.0	101.9	16.5	69.5	42.9
27	89.2	70.7	15.9	204.9	106.9	16.5	69.3	43.5
28	99.3	76.9	17.5	223.4	112.0	16.5	69.0	44.1
29	109.9	83.2	19.2	242.7	117.4	16.5	68.8	44.8
30	120.8	89.8	21.0	262.6	122.9	16.5	68.6	45.4

CONTINUED

Table 7. — Continued

D.b.h. (inches)	FAS	FAS1F	Selects	No. 1C	No. 2C	SW	No. 3A	No. 3B
				TREE GRADE 1, 3-LOGS				
16	7.3	18.0	1.9	54.2	76.5	20.9	75.6	53.3
17	11.7	21.7	2.9	66.8	80.0	20.9	76.3	54.0
18	16.5	25.6	3.9	80.2	83.7	20.9	77.0	54.8
19	21.5	29.7	5.0	94.3	87.6	20.9	77.8	55.6
20	30.1	33.8	6.2	109.2	91.7	20.9	78.6	56.4
21	39.7	40.0	7.4	124.9	96.0	20.9	79.4	57.3
22	49.7	46.5	8.7	141.3	100.5	20.9	80.3	58.2
23	60.2	53.4	10.0	158.5	105.3	20.9	81.2	59.1
24	71.2	60.5	11.4	176.5	110.2	20.9	82.1	60.1
25	82.7	67.9	12.8	195.2	115.4	20.9	83.1	61.2
26	94.6	75.6	14.3	214.7	120.8	20.9	84.2	62.2
27	107.0	83.7	15.9	235.0	126.4	20.9	85.3	63.4
28	119.9	92.0	17.5	256.0	132.2	20.9	86.4	64.5
29	133.3	100.6	19.2	277.8	138.2	20.9	87.5	65.7
30	147.1	109.6	21.0	300.3	144.4	20.9	88.7	67.0
31	161.3	118.8	22.8	323.6	150.8	20.9	90.0	68.3
32	176.1	128.4	24.6	347.7	157.4	20.9	91.3	69.6
33	191.3	138.2	26.6	372.6	164.3	20.9	92.6	71.0
34	207.0	148.4	28.5	398.2	171.4	20.9	94.0	72.4
				TREE GRADE 1, 3½-LOGS				
16	7.3	18.0	1.9	63.1	90.5	25.3	80.0	68.5
17	11.7	21.7	2.9	77.2	94.3	25.3	81.5	69.5
18	16.5	25.6	3.9	92.1	98.4	25.3	83.1	70.6
19	21.5	29.7	5.0	107.9	102.7	25.3	84.8	71.7
20	31.7	33.5	6.2	124.6	107.3	25.3	86.5	73.0
21	43.3	41.4	7.4	142.1	112.1	25.3	88.3	74.2
22	55.5	49.6	8.7	160.4	117.1	25.3	90.3	75.6
23	68.3	58.3	10.0	179.7	122.4	25.3	92.3	77.0
24	81.6	67.3	11.4	199.7	127.9	25.3	94.4	78.5
25	95.5	76.7	12.8	220.7	133.7	25.3	96.6	80.0
26	109.9	86.5	14.3	242.4	139.6	25.3	98.9	81.6
27	124.9	96.6	15.9	265.1	145.8	25.3	101.3	83.2
28	140.5	107.2	17.5	288.5	152.3	25.3	103.7	84.9
29	156.7	118.1	19.2	312.9	158.9	25.3	106.3	86.7
30	173.4	129.4	21.0	338.1	165.9	25.3	108.9	88.6
31	190.7	141.1	22.8	364.1	173.0	25.3	111.7	90.5
32	208.5	153.2	24.6	391.0	180.4	25.3	114.5	92.4
33	226.9	165.6	26.6	418.8	188.0	25.3	117.4	94.5
34	245.9	178.5	28.5	447.4	195.8	25.3	120.4	96.6
				TREE GRADE 2, 1½-LOGS				
13	0.0	3.3	0.0	0.0	18.4	1.5	29.2	28.2
14	1.9	5.9	.0	.0	22.0	1.5	30.2	27.4

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Table 7. — Continued

D.b.h. (inches)	FAS	FAS1F	Selects	No. 1C	No. 2C	SW	No. 3A	No. 3B
15	4.8	8.6	.0	7.7	25.9	1.5	31.2	26.4
16	7.9	11.6	.0	19.5	30.1	1.5	32.3	25.5
17	11.2	14.8	.2	31.9	34.5	1.5	33.5	24.4
18	14.7	18.1	.8	45.2	39.2	1.5	34.7	23.3
19	18.4	21.7	1.5	59.2	44.1	1.5	36.0	22.1
20	22.3	25.4	2.2	73.9	49.3	1.5	37.4	20.9
21	26.4	29.4	2.9	89.4	54.8	1.5	38.8	19.6
22	30.7	33.5	3.6	105.7	60.6	1.5	40.3	18.2
23	35.2	37.8	4.4	122.7	66.6	1.5	41.9	16.8
24	39.9	42.3	5.3	140.5	72.9	1.5	43.6	15.3
				TREE GRADE 2, 2-LOGS				
13	0.0	3.3	0.7	0.0	24.9	6.6	38.2	36.6
14	1.9	5.9	1.1	4.2	29.6	6.6	39.5	35.8
15	4.8	8.6	1.5	15.9	34.6	6.6	40.9	35.1
16	7.9	11.6	1.9	28.5	40.0	6.6	42.4	34.3
17	11.2	14.8	2.3	41.8	45.8	6.6	44.0	33.4
18	14.7	17.9	2.7	56.0	51.8	6.6	45.6	32.5
19	18.4	21.9	3.2	70.9	58.3	6.6	47.4	31.5
20	22.3	26.0	3.7	86.7	65.1	6.6	49.3	30.5
21	26.4	30.4	4.3	103.3	72.2	6.6	51.2	29.4
22	30.7	34.9	4.8	120.6	79.7	6.6	53.3	28.3
23	35.2	39.7	5.4	138.8	87.5	6.6	55.4	27.1
24	39.9	44.7	6.0	157.8	95.7	6.6	57.7	25.8
25	44.7	49.9	6.7	177.6	104.2	6.6	60.0	24.6
26	49.8	55.3	7.3	198.3	113.1	6.6	62.5	23.2
27	55.1	60.9	8.0	219.7	122.3	6.6	65.0	21.8
28	60.6	66.8	8.7	241.9	131.9	6.6	67.6	20.4
				TREE GRADE 2, 2½-LOGS				
13	0.0	3.3	3.3	0.0	31.3	11.6	47.2	44.9
14	1.9	5.9	3.6	11.7	37.1	11.6	48.8	44.3
15	4.8	8.6	3.8	24.1	43.3	11.6	50.6	43.7
16	7.9	11.6	4.1	37.5	50.0	11.6	52.5	43.1
17	11.2	14.8	4.4	51.7	57.0	11.6	54.4	42.4
18	14.7	17.7	4.7	66.7	64.5	11.6	56.6	41.7
19	18.4	22.0	5.0	82.7	72.5	11.6	58.8	40.9
20	22.3	26.6	5.3	99.4	80.8	11.6	61.1	40.1
21	26.4	31.3	5.6	117.1	89.6	11.6	63.6	39.2
22	30.7	36.3	6.0	135.6	98.8	11.6	66.2	38.3
23	35.2	41.6	6.4	154.9	108.4	11.6	68.9	37.4
24	39.9	47.0	6.8	175.2	118.5	11.6	71.8	36.4
25	44.7	52.7	7.2	196.3	129.0	11.6	74.7	35.4
26	49.8	58.7	7.6	218.2	139.9	11.6	77.8	34.3
27	55.1	64.8	8.1	241.0	151.3	11.6	81.0	33.2
28	60.6	71.2	8.5	264.7	163.1	11.6	84.3	32.0

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Table 7. — Continued

D.b.h. (inches)	FAS	FAS1F	Selects	No. 1C	No. 2C	SW	No. 3A	No. 3B
				TREE GRADE 2, 3-LOGS				
13	0.0	3.3	6.0	6.8	37.8	16.6	56.2	53.3
14	1.9	5.9	6.1	19.1	44.7	16.6	58.1	52.8
15	4.8	8.6	6.2	32.3	52.0	16.6	60.3	52.4
16	7.9	11.6	6.3	46.5	59.9	16.6	62.5	51.9
17	11.2	14.8	6.4	61.5	68.3	16.6	64.9	51.4
18	14.7	17.5	6.6	77.5	77.2	16.6	67.5	50.8
19	18.4	22.2	6.7	94.4	86.6	16.6	70.2	50.3
20	22.3	27.1	6.9	112.2	96.5	16.6	73.0	49.7
21	26.4	32.3	7.0	130.9	107.0	16.6	76.0	49.0
22	30.7	37.7	7.2	150.5	117.9	16.6	79.2	48.4
23	35.2	43.4	7.4	171.1	129.4	16.6	82.5	47.7
24	39.9	49.4	7.5	192.5	141.3	16.6	85.9	46.9
25	44.7	55.6	7.7	214.9	153.8	16.6	89.5	46.2
26	49.8	62.0	7.9	238.1	166.7	16.6	93.2	45.4
27	55.1	68.7	8.1	262.3	180.2	16.6	97.0	44.5
28	60.6	75.7	8.3	287.4	194.2	16.6	101.1	43.7
29	66.3	82.9	8.6	313.4	208.7	16.6	105.2	42.8
30	72.2	90.4	8.8	340.4	223.7	16.6	109.5	41.9
				TREE GRADE 3, 1-LOG				
10	0.0	0.0	1.0	0.0	1.6	3.5	9.2	14.5
11	.0	.0	1.0	.0	4.7	4.0	12.1	12.0
12	.2	.0	.9	5.5	8.1	4.7	15.4	9.3
13	.6	1.6	.9	12.7	11.7	5.3	18.9	6.3
14	1.1	3.6	.9	20.4	15.7	6.0	22.7	3.1
15	1.5	5.8	.8	28.7	20.0	6.8	26.7	.0
16	2.0	8.1	.8	37.6	24.5	7.6	31.1	.0
				TREE GRADE 3, 1½-LOGS				
10	0.0	0.0	0.2	0.0	11.7	8.2	20.7	28.7
11	.0	.0	.3	.0	14.7	8.5	22.9	27.4
12	.0	.0	.4	5.5	18.1	8.9	25.4	25.9
13	.4	1.6	.5	12.7	21.7	9.3	28.0	24.3
14	1.2	3.6	.7	20.4	25.7	9.8	30.9	22.6
15	2.1	5.8	.8	28.7	29.9	10.3	33.9	20.7
16	3.0	8.1	1.0	37.6	34.4	10.8	37.2	18.7
17	3.9	10.5	1.2	47.1	39.2	11.3	40.7	16.6
18	5.0	13.2	1.4	57.1	44.3	11.9	44.4	14.4
19	6.0	15.9	1.6	67.8	49.7	12.6	48.3	12.0
20	7.2	18.8	1.8	78.9	55.4	13.2	52.4	9.5
				TREE GRADE 3, 2-LOGS				
12	0.0	0.0	0.0	5.5	28.1	13.2	35.4	42.5
13	.2	1.6	.2	12.7	31.7	13.4	37.2	42.3

CONTINUED

Table 7. — Continued

D.b.h. (inches)	FAS	FAS1F	Selects	No. 1C	No. 2C	SW	No. 3A	No. 3B
14	1.3	3.6	.5	20.4	35.6	13.5	39.1	42.0
15	2.6	5.8	.8	28.7	39.8	13.7	41.1	41.8
16	3.9	8.1	1.2	37.6	44.2	13.9	43.3	41.5
17	5.3	10.5	1.6	47.1	49.0	14.2	45.7	41.2
18	6.8	13.2	2.0	57.1	54.0	14.4	48.1	40.8
19	8.4	15.9	2.4	67.8	59.4	14.7	50.8	40.5
20	10.0	18.8	2.9	78.9	65.0	14.9	53.5	40.1
21	11.8	21.9	3.4	90.7	70.9	15.2	56.4	39.7
22	13.6	25.1	3.9	103.1	77.1	15.5	59.5	39.3
23	15.5	28.5	4.4	116.0	83.6	15.8	62.7	38.9
24	17.5	32.0	5.0	129.5	90.4	16.1	66.0	38.4
				TREE GRADE 3, 2½-LOGS				
16	4.8	8.1	1.4	37.6	54.1	17.1	49.5	64.2
17	6.7	10.5	2.0	47.1	58.8	17.0	50.6	65.7
18	8.6	13.2	2.7	57.1	63.8	16.9	51.9	67.2
19	10.7	15.9	3.3	67.8	69.1	16.8	53.2	68.9
20	12.9	18.8	4.1	78.9	74.6	16.6	54.6	70.6
21	15.2	21.9	4.8	90.7	80.5	16.5	56.1	72.5
22	17.6	25.1	5.6	103.1	86.6	16.4	57.7	74.4
23	20.1	28.5	6.4	116.0	93.0	16.3	59.3	76.4
24	22.7	32.0	7.3	129.5	99.7	16.1	61.0	78.5
25	25.5	35.6	8.2	143.5	106.7	16.0	62.7	80.7
26	28.3	39.5	9.1	158.2	114.0	15.8	64.6	83.0
27	31.3	43.4	10.1	173.4	121.5	15.6	66.5	85.4
28	34.3	47.5	11.1	189.2	129.3	15.5	68.5	87.8

Table 8. — Thickness distribution by lumber grade for yellow birch, in percent

Lumber thickness (inches)	FAS	FAS1F	Selects	1C	2C	3A	3B
3/8	—	—	—	—	—	0.1	0.2
2/4	—	—	0.1	—	—	—	.1
5/8	0.1	—	—	—	—	—	.3
3/4	.7	0.8	2.9	2.3	1.6	2.9	3.5
4/4	44.4	43.2	56.8	64.5	69.0	71.8	66.3
5/4	40.6	35.4	32.0	27.4	25.3	19.4	10.4
6/4	5.9	11.2	7.2	4.3	2.3	.3	.2
8/4	—	—	—	.1	1.2	5.2	17.9
10/4	8.3	9.4	1.0	1.4	.6	.3	1.1

Table 9. — Thickness distribution by lumber grade for red maple, in percent

Lumber thickness (inches)	FAS	FAS1F	Selects	1C	2A	2B	3A	3B
3/8	—	—	—	—	—	—	0.1	—
5/8	—	—	—	—	—	—	.1	—
3/4	0.2	0.1	—	1.0	1.4	2.4	1.1	4.1
4/4	52.4	58.1	59.2	71.3	64.0	78.7	67.6	82.9
5/4	11.7	18.2	8.9	11.3	12.7	18.1	3.6	13.0
6/4	18.4	16.8	19.1	10.6	1.8	.4	.3	—
7/4	—	.5	—	—	.1	—	.1	—
8/4	17.3	6.3	12.8	5.8	10.6	.4	18.0	—
10/4	—	—	—	—	9.4	—	9.1	—

Table 10. — Thickness distribution by lumber grade for black oak, in percent

Lumber thickness (inches)	FAS	FAS1F	Selects	1C	2C	SW	3A	3B
2/4	0.1	0.1	—	—	0.1	—	—	—
3/4	.7	—	0.5	0.8	.8	1.0	0.6	0.1
4/4	7.6	13.4	26.2	32.9	57.2	64.1	57.9	36.2
5/4	91.2	85.8	71.1	64.6	32.6	15.4	7.7	2.1
6/4	.4	.7	—	.3	.3	—	.2	—
7/4	—	—	—	.1	—	.5	—	.2
8/4	—	—	2.2	1.2	8.4	18.2	27.9	36.2
10/4	—	—	—	—	—	—	3.4	22.5
12/4	—	—	—	.1	.6	.8	2.3	2.7

Table 11. — Mean lumber volumes, standard errors of the residuals, and correlation coefficients for yellow birch

Lumber grade	Mean lumber volume (board feet)	Standard error of the residual (board feet)	Correlation coefficient
TREE GRADE 1 (BASIS: 63 TREES)			
FAS	55.91	43.16	0.729
FAS1F	34.98	20.56	.558
Selects	9.14	9.21	.202
No. 1C	85.20	45.04	.834
No. 2C	65.54	33.08	.681
No. 3A	41.21	19.96	.738
No. 3B	35.08	21.39	.452
TREE GRADE 2 (BASIS: 71 TREES)			
FAS	14.91	18.11	0.556
FAS1F	14.98	12.76	.530
Selects	6.24	7.69	.083
No. 1C	49.65	26.45	.598
No. 2C	49.37	18.54	.815
No. 3A	35.07	17.59	.509
No. 3B	31.37	19.38	.522
TREE GRADE 3 (BASIS: 61 TREES)			
FAS	1.16	2.89	0.325
FAS1F	4.62	6.57	.531
Selects	1.89	4.07	.067
No. 1C	22.96	14.05	.861
No. 2C	37.66	16.60	.819
No. 3A	27.69	14.25	.695
No. 3B	27.69	13.20	.472

Table 12. — Mean lumber volumes, standard errors of the residuals, and correlation coefficients for red maple

Lumber grade	Mean lumber volume (board feet)	Standard error of the residual (board feet)	Correlation coefficient
TREE GRADE 1 (BASIS: 70 TREES)			
FAS	70.26	59.31	0.563
FAS1F	54.88	29.54	.544
Selects	17.71	11.93	.497
No. 1C	70.37	27.92	.772
No. 2A	72.96	31.64	.712
No. 2B	49.97	24.41	.256
No. 3A	23.99	19.69	.483
No. 3B	13.66	9.63	.692
TREE GRADE 2 (BASIS: 80 TREES)			
FAS	22.05	23.41	0.601
FAS1F	26.63	17.24	.648
Selects	10.92	9.52	.326
No. 1C	39.86	21.04	.722
No. 2A	57.94	30.22	.405
No. 2B	50.15	33.83	.178
No. 3A	16.42	16.07	.324
No. 3B	8.95	11.81	.566
TREE GRADE 3 (BASIS: 128 TREES)			
FAS	4.11	8.99	0.533
FAS1F	8.95	13.21	.658
Selects	6.54	6.72	.581
No. 1C	22.48	16.46	.764
No. 2A	37.45	25.03	.609
No. 2B	48.40	28.97	.446
No. 3A	15.71	16.67	.434
No. 3B	8.30	13.11	.364

Table 13. — Mean lumber volumes, standard errors of the residuals, and correlation coefficients for black oak

Lumber grade	Mean lumber volume (board feet)	Standard error of the residual (board feet)	Correlation coefficient
TREE GRADE 1 (BASIS: 71 TREES)			
FAS	54.99	35.24	0.803
FAS1F	53.50	30.78	.753
Selects	11.82	13.98	.426
No. 1C	185.11	72.57	.814
No. 2C	111.66	48.37	.619
SW	20.49	25.14	.216
No. 3A	83.66	31.40	.510
No. 3B	59.93	45.56	.486
TREE GRADE 2 (BASIS: 62 TREES)			
FAS	25.06	24.08	0.655
FAS1F	25.12	16.73	.802
Selects	4.94	6.66	.376
No. 1C	90.54	32.92	.934
No. 2C	74.39	31.93	.837
SW	9.78	10.99	.444
No. 3A	59.95	28.61	.614
No. 3B	37.02	38.53	.312
TREE GRADE 3 (BASIS: 48 TREES)			
FAS	5.19	11.79	0.592
FAS1F	13.15	13.74	.770
Selects	2.96	5.15	.570
No. 1C	57.25	27.89	.916
No. 2C	41.54	22.97	.852
SW	12.52	12.60	.371
No. 3A	42.25	26.53	.608
No. 3B	40.49	39.11	.570

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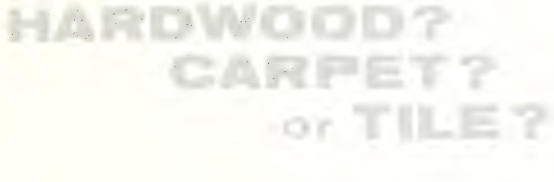

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TO SELECT A FLOORING MATERIAL

INITIAL INSTALLATION cost, annual maintenance cost, and total long-term cost are important in the purchase of flooring products. Before deciding on a flooring material, the prudent buyer will consider each of these in relation to his personal desires. From these evaluations, he will then be able to select the flooring material that is best suited to his individual needs.

Unfortunately very little information about these costs has been made available to the potential buyer. Most of the available information is in the form of claims by the manufacturers about their own products. When the buyer attempts to compare these claims, he finds that many of them are conflicting. Consequently he is unable to make the objective comparisons between products to determine the most appropriate material for his individual situation.

In an attempt to help alleviate this problem, we recently conducted a study to obtain unbiased information about the various flooring materials used under residential conditions. From our data we concluded that, when compared with composition tile and wall-to-wall carpeting, hardwood flooring has the lowest annual maintenance cost and lowest long-term cost. From the information contained in this report, the prospective buyer can make his own comparisons to determine the flooring material that suits him best.

THE STUDY

Our study was designed to determine and compare annual and long-term flooring costs based on the initial installation cost, the maintenance cost, and the wear life of the flooring material. We also attempted to determine the time and effort required to maintain each of the principal types of flooring material used under residential conditions.

Although single-family homes constitute the largest percentage of dwelling units, they vary greatly in size, type of structure, and costs. Also, accurate long-term records of wear life and major maintenance costs are very difficult to obtain for single-family homes, because of the relatively rapid owner turnover. Consequently we decided to use apartment buildings for our study because they represent a more standardized and compact unit to work with and because more accurate maintenance information is available for them.

Nine cities—Atlanta, Boston, Chicago, Denver, Houston, Los Angeles, New York, St. Louis, and Washington—were selected for inclusion in the study. We felt that this range of sampling would allow for the variation in flooring materials used throughout the Nation and would help us measure flooring costs and wear under different living and climatic conditions.

In each city, eight apartment buildings were selected for detailed study. We used four high-rise buildings and four garden-type buildings, two of each under 10 years old and two over 10 years old. This sampling procedure took into account different construction methods and newer flooring materials as well as the older types.

The types of flooring materials included were asphalt tile, vinyl asbestos tile, hardwood strip, hardwood block, nylon carpet, and wool carpet. For comparison these were combined into composition tile (asphalt and vinyl asbestos), hardwood (strip and block), and carpet (nylon and wool). The data were collected and analyzed in two phases.

Phase I.—Phase I was a personal interview with the owner or manager of each apartment building, to gather detailed information about their experiences with the various types of

flooring. From this information, we determined the installation costs of the various types of flooring, how often they were maintained by the owner, the cost of this maintenance, and the actual wear life. We also obtained information about room dimensions and flooring specifications.

Phase II.—In phase II, a subsample of individual apartment tenants in each building was selected for interview by mailed questionnaire. From this questionnaire we found out the time and effort the average housewife spends to maintain her floors, the materials required for maintenance, and her opinions of the different flooring materials. From these observations we were able to estimate the time, effort, and materials required to maintain each of the principal types of flooring.

RESULTS

The data were analyzed and evaluated from the standpoint of a single-family-home owner. That is, the data collected from the building owner were combined with the data collected from the apartment tenant to estimate the installation and maintenance costs that the owner of a single-family home would experience.

Apartment Building Owner

Composition tile had the lowest average installation cost—$35.00 per 100 square feet—and an average wear life of 17.7 years (table 1). Hardwood flooring had the highest average installation cost—$60.00 per 100 square feet—but had a total wear life of over 50 years. Carpet had an installation cost to that of hardwood—$58.61 per 100 square feet—but had the lowest average wear life, 7.5 years.

Also included in the reported cost of hardwood flooring was a complete resanding and refinishing every 9.5 years at an average cost of $11.97 per 100 square feet. The average total annual costs per 100 square feet to the building owners for the various types of flooring materials were: $2.726 for composition tile, $3.022 for hardwood, and $10.458 for carpet.

Table 1.— Apartment owners' long-term cost of living room floors

[Based on interviews with 72 building managers or owners]

Type of flooring material and cost element	Item
Asphalt tile:	
Installation cost/100 square feet	$27.50
Wear life, years	16.7
Minor maintenance cost/100 square feet/year	$ 0.503
Total annual cost/100 square feet	$ 2.130
Vinyl asbestos tile:	
Installation cost/100 square feet	$42.50
Wear life, years	18.7
Minor maintenance cost/100 square feet/year	$ 1.036
Total annual cost/100 square feet	$ 3.321
Hardwood strip flooring:	
Installation cost/100 square feet	$60.00
Wear life, years	50+
Major maintenance cost/100 square feet	$11.97
Average frequency of major maintenance, years	9.5
Minor maintenance cost/100 square feet/year	$ 0.576
Total annual cost/100 square feet	$ 3.036
Hardwood block flooring:	
Installation cost/100 square feet	$60.00
Wear life, years	50+
Major maintenance cost/100 square feet	$11.97
Average frequency of major maintenance, years	9.5
Minor maintenance cost/100 square feet/year	$ 0.549
Total annual cost/100 square feet	$ 3.009
Nylon carpet:	
Installation cost/square yard	$ 4.49
Installation cost/100 square feet	$49.88
Wear life, years	6
Major maintenance cost/100 square feet/year	$ 2.517
Average frequency of major maintenance, years	1.62
Total annual cost/100 square feet	$10.830
Wool carpet:	
Installation cost/square yard	$ 6.06
Installation cost/100 square feet	$67.33
Wear life, years	9
Major maintenance cost/100 square feet/year	$ 2.606
Average frequency of major maintenance, years	1.75
Total annual cost/100 square feet	$10.087

Apartment Tenant

Separate information was provided by the housewives for the living room, bedroom, and dining room areas in their apartments. This allowed for comparison of flooring types under different room-use conditions.

Living Room.—Data from the questionnaires indicated that a

Table 2. — Average minor maintenance costs[1] (professional carpet cleaning separate), by type of flooring and rug coverage area

[In dollars/100 square feet/year]

Floor type	Percent of rug coverage				
	0-20	20-40	40-60	60-80	80-100
	LIVING ROOM[1]				
Composition tile	9.89	3.91	3.56	2.17	2.21
Hardwood flooring	4.21	1.32	4.57	1.82	1.90
Carpet (wall-to-wall)	—	—	—	—	1.63
Professional carpet-cleaning costs	0	1.16	2.20	2.32	6.35
	BEDROOM[1]				
Composition tile	5.20	(*)	2.60	1.18	2.91
Hardwood flooring	3.24	5.15	1.62	7.63	1.62
Carpet (wall-to-wall)	—	—	—	—	1.36
Professional carpet-cleaning costs	0	1.56	2.26	4.21	4.52
	DINING ROOM[2]				
Composition tile	6.90	(*)	(*)	(*)	1.69
Hardwood flooring	5.06	2.08	0.50	2.65	2.72
Carpet (wall-to-wall)	—	—	—	—	1.92
Professional carpet-cleaning costs	0	1.51	2.41	4.68	9.97

[1] Based on responses from 760 housewives. Minor maintenance costs were calculated from maintenance frequencies and type of maintenance materials used as reported by the housewives together with maintenance materials prices and expected coverage reported by the manufacturing companies.

[2] Based on responses from 459 housewives.

* Insufficient data

tenant spent $9.89 per 100 square feet per year for floor maintenance in a living room completely covered with composition tile (table 2). This compared with $4.21 for maintaining a hardwood floor. Wall-to-wall carpet cost the tenant $7.98 to $8.56 per 100 square feet per year, depending on whether it was owned by the tenant or building owner. By far the greatest part of the carpet expense was for professional carpet cleaning, which averaged $6.35 per 100 square feet per year.

Bedroom.—In general, the maintenance costs for the various floor types were less in the bedrooms than in the living rooms. For wall-to-wall carpet in the bedroom, the tenants spent on the average of $5.88 to $7.43 per 100 square feet per year, depending on whether the carpet was owned by the tenant or the building owner. This compared with $5.20 for maintaining a floor completely covered with composition tile and $3.24 for maintaining a hardwood floor.

Table 3. — Summary of average minor maintenance costs,[1] by type of flooring and rug-coverage area

[In dollars/100 square feet/year]

Floor type	Percent of rug coverage				
	0-20	20-40	40-60	60-80	80-100
			LIVING ROOM		
Composition tile	9.89	5.07	5.76	4.49	8.56
Hardwood flooring	4.21	2.48	6.77	4.14	8.25
Carpet (wall-to-wall)	—	—	—	—	7.98
			BEDROOM		
Composition tile	5.20	(*)	4.86	5.39	7.43
Hardwood flooring	3.24	6.71	3.88	11.84	6.14
Carpet (wall-to-wall)	—	—	—	—	5.88
			DINING ROOM		
Composition tile	6.90	(*)	(*)	(*)	11.66
Hardwood flooring	5.06	3.59	2.91	7.33	12.69
Carpet (wall-to-wall)	—	—	—	—	11.89

[1] Includes cost of professional carpet cleaning.
* Insufficient data

In the bedrooms, carpet was the most expensive to maintain, but over half of the cost was accounted for by professional cleaning (table 2).

Dining Room.—Average floor maintenance costs in the dining rooms were the highest for wall-to-wall carpet and hardwood. Average maintenance cost for wall-to-wall carpet ranged from $11.66 to $12.69 per 100 square feet per year. This was the highest maintenance cost of any floor type in any room. But almost $10.00 of this was due to professional cleaning cost. The average maintenance cost for hardwood was $5.06 per 100 square feet per year. This compared with $6.90 for composition tile (table 2). A complete summary of the tenants' maintenance expenses in each of the three rooms is given in table 3.

Single-Family-Home Owners

Total Annual Costs

We combined the cost to the building owner with the cost to a tenant to estimate total flooring cost for a single-family-home owner. The owner costs were the installation cost in relation to wear life, plus sanding and refinishing costs. Tenant costs were those of maintenance only.

In annual cost per 100 square feet, hardwood floors showed a definite economic advantage when compared to composition tile or wall-to-wall carpet. In the living rooms hardwood floors had an annual cost of $6.67 compared to $11.87 for composition tile and $16.09 for wall-to-wall carpet. In the bedrooms hardwood floors had an annual cost of $5.70 compared to $7.18 for composition tile and $14.20 for wall-to-wall carpet. In the dining rooms annual costs were $7.52, $7.88, and $19.89 for hardwood, composition tile, and wall-to-wall carpet respectively.

A tabulation of estimated costs to a single-family-home owner is given in table 4.

Table 4. — Estimated long-term flooring costs for single-family-home owners, by type of room and type of flooring

Type of flooring material and cost element	Living room	Bedroom	Dining room
Composition tile:			
Installation cost/100 sq. ft.	$35.00	$35.00	$35.00
Wear life, years	17.7	17.7	17.7
Minor maintenance costs/ 100 sq. ft./year	$ 9.89	$ 5.20	$ 6.90
Total annual cost/100 sq. ft./year	$11.87	$ 7.18	$ 7.88
Hardwood flooring:			
Installation cost/100 sq. ft.	$60.00	$60.00	$60.00
Wear life, years	50+	50+	50+
Major maintenance cost/100 sq. ft. every 9.5 years	$11.97	$11.97	$11.97
Minor maintenance cost/100 sq. ft./year	$ 4.21	$ 3.24	$ 5.06
Total annual cost/100 sq. ft./year	$ 6.67	$ 5.70	$ 7.52
Carpet (wall-to-wall):			
Installation cost/sq. yd.	$ 5.28	$ 5.28	$ 5.28
Installation cost/100 sq. ft.	$58.61	$58.61	$58.61
Wear life, years	7.5	7.5	7.5
Minor maintenance cost/100 sq. ft./year (professional cleaning)	$ 6.35	$ 4.52	$ 9.97
Minor maintenance cost/100 sq. ft./year	$ 1.92	$ 1.86	$ 2.10
Total annual cost/100 sq. ft./year	$16.09	$14.20	$19.89

Maintenance Time

Costs alone do not provide a complete picture. The time spent maintaining the different flooring materials is also important.

Living Room.—The questionnaires received from the tenants indicated that the average housewife spent 44.4 hours per 100 square feet per year maintaining composition tile in her living room, compared to 21.8 hours for hardwood flooring and 14.1 to 21.1 hours for wall-to-wall carpet (average 16.0 hours). All times for the living room are shown in table 5.

Bedroom.—Composition tile in the bedrooms required 37.2

Table 5. — Average time spent[1] for floor maintenance, by type of flooring and rug-coverage area

[In hours/100 square feet/year]

Floor type	Percent of rug coverage				
	0-20	20-40	40-60	60-80	80-100
	LIVING ROOM				
Composition tile	44.4	34.0	41.6	52.1	21.1
Hardwood flooring	21.8	17.9	34.4	28.2	14.1
Carpet (wall-to-wall)	—	—	—	—	14.1
	BEDROOM				
Composition tile	37.2	(*)	31.5	34.0	21.2
Hardwood flooring	23.9	30.7	17.8	41.9	14.2
Carpet (wall-to-wall)	—	—	—	—	16.3
	DINING ROOM				
Composition tile	102.0	(*)	(*)	(*)	27.1
Hardwood flooring	36.4	32.3	22.3	52.8	23.5
Carpet (wall-to-wall)	—	—	—	—	36.1

[1] Weighted average of all flooring types with 80-100 percent rug coverage is 16.6 hours/100 square feet/year.

* Insufficient data

hours per 100 square feet per year to maintain as compared to 23.9 hours for hardwood flooring and 14.2 to 21.2 hours for wall-to-wall carpet (average 16.6 hours). All times reported for bedroom floors are shown in table 5.

Dining Room.—Maintenance time requirements for dining room floors were considerably higher than for the other two rooms. Housewives reported 102.0 hours per 100 square feet per year needed to maintain composition tile floors under dining room conditions, compared to 36.4 hours for hardwood flooring and 23.5 to 36.1 hours for wall-to-wall carpet (average 29.9 hours). All dining room times are shown in table 5.

Flooring Preferences

Housewives' relative preferences for the different types of flooring materials were also studied. This was done by analyzing their answers to the question: "If you decided tomorrow

to build a new home, what type of flooring or floor covering would you prefer for the living room, the dining room, and the bedrooms?"

Living Room.—When the answers for the living room were analyzed, it soon became apparent that housewives' preferences between hardwood and carpet were closely associated with the type of flooring material they had been living with. Approximately 65 percent of the people who had hardwood floors said they would prefer hardwood in a new home; the rest preferred wall-to-wall carpet. Of the people who had wall-to-wall carpet, about 67 percent said they wanted carpet; the rest wanted hardwood floors.

But of the people who had composition tile, only 10 percent said they would put it in the living room of a new home. About 40 percent preferred hardwood, and 50 percent preferred wall-to-wall carpet.

Hence 10 percent of all respondents had composition tile but only 4 percent of all respondents would put it in the living room of their new home. Similarly, 66 percent of the respondents had wall-to-wall carpet or a floor more than 60 percent covered with carpet, and 57 percent of the respondents said that they would prefer wall-to-wall carpet in a new home. Hardwood floors were represented by 24 percent of the respondents, but 38 percent of the respondents said that they would prefer hardwood in a new home. All of the preference data for living rooms are presented in table 6.

Bedroom.—Preferences for flooring materials in the bedrooms were similar to those for living rooms. Approximately 65 percent of the people who had hardwood floors said they would prefer hardwood for the bedrooms in a new home; 29 percent preferred wall-to-wall carpet. Of the people who had wall-to-wall carpet, about 68 percent said they wanted carpet; 26 percent wanted hardwood floors. Again, of the people who had composition tile in the bedrooms, only 13 percent said they would put it in a new home. The remaining preferences were split evenly between hardwood and carpet, with 43 percent each. All of the preference data for the bedrooms are presented in table 6.

Table 6. — Preferences for flooring, by type of flooring and rug-coverage area

[In percent]

Type of flooring respondents now have	Percent of total	Floor type preferred in a new home: Composition tile	Hardwood flooring	Carpet, wall-to-wall	Other	Total
		LIVING ROOM				
Composition tile (less than 60% covered)	10	10	39	51	0	100
Hardwood flooring (less than 60% covered)	24	(*)	65	33	2	100
Carpet (wall-to-wall) (over 60% covered)	66	4	28	67	1	100
Percent of total	100	4	38	57	1	100
		BEDROOM				
Composition tile (less than 60% covered)	15	13	43	43	1	100
Hardwood flooring (less than 60% covered)	38	4	65	29	2	100
Carpet (wall-to-wall) (over 60% covered)	47	4	26	68	2	100
Percent of total	100	5	43	50	2	100
		DINING ROOM				
Composition tile (less than 60% covered)	12	42	31	27	0	100
Hardwood flooring (less than 60% covered)	34	18	60	20	2	100
Carpet (wall-to-wall) (over 60% covered)	54	14	26	56	4	100
Percent of total	100	19	39	40	2	100

* Less than 1 percent.

Dining Room.—Housewives' preferences for dining room flooring were considerably different from those for the living room and bedrooms. For the dining room, of the people who had composition tile, 42 percent said they would also put it in a new home, 31 percent would switch to hardwood, and 27 percent preferred carpet.

Of the people who had hardwood floors, 60 percent would

put hardwood in a new home, 20 percent would go to carpet, and 18 percent would prefer composition tile. Similarly, of those who had carpet, 56 percent would prefer to have it in the dining room of a new home, 26 percent would prefer hardwood, and 14 percent would prefer composition tile.

Although 54 percent of all the respondents had wall-to-wall carpet or a floor more than 60 percent covered with carpet, only 40 percent of the respondents said they would prefer carpet in the dining room of a new home. Composition tile floors were represented by 12 percent of the respondents, but 19 percent of the respondents stated they would prefer it in a new home. Similarly, hardwood floors were represented by 34 percent of the respondents, but 39 percent preferred hardwood. All dining room preference data are presented in table 6.

Ease and Expense of Maintenance

We also attempted to obtain the housewives' opinions about the ease and expense of maintaining the various types of flooring. However, the data turned out to be rather inconclusive.

The closest that the respondents came to a consensus was in designating wall-to-wall carpet as the easiest to care for; 59 percent of the respondents so indicated (table 7). For the other types of flooring, no clear pattern of opinion could be found in the response to the question about maintenance ease or expense.

Table 7. — Opinions of housewives about ease and expense of maintaining living room floor surfaces, by type of flooring, in percentage of response

Rating	Composition tile	Hardwood flooring	Large rug on wood or tile	Wall-to-wall carpet	Total
Easiest	6	20	15	59	100
Most difficult	33	39	14	14	100
Cheapest	28	26	12	34	100
Most expensive	12	32	8	48	100

DISCUSSION

Every attempt was made in this study to obtain typical or representative samples from the real world. We wanted data on the actual costs encountered and the actual procedures used by the average housewife in maintaining different flooring materials. For instance, we found that over 40 percent of the housewives who had hardwood floors wet-mopped them. This procedure, though not recommended by manufacturers, does occur in real life and must be accounted for in any estimate of maintenance time. Waxing was also performed much more frequently than manufacturers recommend or believe to be necessary.

We collected data only on medium-rental apartments because neither luxury nor low-rent housing could be considered typical. We also used both high-rise and garden-type apartments to take into account differences in building constuction and flooring types.

Every attempt was made to eliminate bias. We believe the results are representative of the true relative costs for maintaining the various types of flooring materials used under residential conditions.

Apartment Building Owner

The apartment owner is a businessman; so factors affecting operating costs such as installation cost, wear life, and maintenance costs of the floors are important to him.

Installation Costs

The estimates of installation costs used for smooth-surface floors in this report are not those given by the building owner. Since many of these floors were installed over 15 years ago, the quoted costs were unrealistic for today's conditions.

For tile floors the installation costs used were those published by the Wharton School of Finance and Commerce in a recent study (*Parks 1966*).

For hardwood flooring, after consulting with hardwood floor-

ing manufacturers, flooring contractors, and builders, we selected the installed price of $60 per 100 square feet. We believe this figure represents the majority of installations. Several companies quoted prices in the range of $45 to $58.

For wall-to-wall carpet the installed cost is that quoted by the building owners. Because of the relatively short life of this material, these prices were considered to be current. The costs used included carpet, pad, labor, and accessories such as door strips. The total installation cost for nylon carpet averaged $4.49 per square yard, and the cost for wool carpet averaged $6.06 per square yard.

Wear Life

The wear-life values reported by the building owners are very close to those expected by the manufacturers. The Asphalt and Vinyl Tile Institute (*1963*) estimated that wear life is 15 years for asphalt tile and 20 years for vinyl asbestos. These correspond closely with the values found in this study.

The wear life of hardwood flooring is generally considered to be the life of the building. However, the reported frequency of complete resanding and refinishing every 9.5 years is greater than most hardwood flooring manufacturers predict.

The reported wear life for carpet is slightly higher than that predicted by the general rule of thumb of 1 year of wear life per dollar of installation cost per square yard. This additional life may be due to better manufacturing methods, better maintenance methods, or to lower acceptable appearance levels used by the apartment building owners to determine when the carpets need replacement.

Maintenance Costs

Maintenance costs to the building owner generally result from getting a vacated apartment ready for new tenants. So these costs are related to tenant turnover. In general, the turnover is low in the Northeast and parts of the South where hardwood and asphalt tile are the principal flooring materials. In the rest of the Nation, especially the West, turnover is high; in these areas carpet and vinyl asbestos are more commonly

used. The difference in turnover obviously has some effect on the relative maintenance cost for the different types of flooring.

The average maintenance cost for vinyl asbestos flooring was also higher because of the policy of one building owner who periodically waxed and buffed the floors while the tenants were in the apartments. Although his practices were logical, his costs were higher; and they did raise the average. If his costs were not included, the average maintenance cost for vinyl asbestos would have been similar to that for asphalt tile.

Most building owners felt they could clean the carpets and in some cases lift the pile for 4 to 4.5 cents per square foot, and some indicated they could do it for as little as 3 cents. Others hired the cleaning done, and their costs were slightly higher.

In addition to waxing and buffing the floors, the building owners who had hardwood floors had the cost of complete re-sanding and refinishing. This cost is comparable to the cost for complete replacement of the other types of flooring. It would also occur to the single-family-home owner, so it was included in the estimate of his costs. Note that the 9.5 year frequency was the average for the owners who did refinish their floors. Several owners had hardwood floors much older than 9.5 years but had never resanded or refinished. For example, one building had a stained oak parquet floor that was over 20 years old and had not been refinished.

Although the total flooring cost will differ from building to building, the relative owner costs of the various types of flooring should remain constant—hardwood and composition tile were the least expensive and carpet the most expensive.

Apartment Tenant

The apartment tenant, in contrast to the apartment owner, was not concerned with installation cost or wear life of the flooring material. Her main expense, other than professional carpet cleaning, was the out-of-pocket cost for maintenance materials such as waxes, strippers, shampoos, and spot cleaners. These are the minor maintenance costs.

Minor Maintenance Material Costs

In calculating maintenance cost, we separated cost of minor maintenance materials and cost of professional carpet cleaning (table 2).

The percent of rug coverage was considered the percent of room area covered by rug or carpet. The values for 0 to 20 percent coverage are costs for maintaining only smooth-surface flooring. All times and costs for maintaining any rugs in the 0-to-20-percent class were disregarded because these would be small throw rugs, which could be easily moved and washed in a washing machine. Likewise, the values given in the 80-to-100-percent class pertain only to the cost of maintaining carpet in a room. Any costs reported for smooth-surface floors were disregarded in this class because they would represent a small area around the edge of the room or under furniture.

For example, in table 2, the $9.89 for composition tile and $4.21 for hardwood are costs per year to wax and strip 100 square feet of room area having these types of floors. The $3.91 for composition tile 20-to-40-percent covered is for both wax and other materials used on the floor and for shampoo and spot remover used on the carpet. However, the $2.21 for composition tile 80-to-100-percent covered is only for shampoo and spot remover used on the carpet at home. None of this cost pertains to composition tile because none or very little of it was showing. All of these costs are based on the frequency of maintenance, the types of products used and their prices, and the coverage obtained from these products.

Professional Carpet-Cleaning Costs

The professional carpet-cleaning costs were the average costs to the tenants for hiring someone to clean their carpet either in their apartment or at a cleaning establishment. A cost of $8.32 per 100 square feet of carpet per year was the average cost for the housewives who had their living room carpets professionally cleaned, regardless of carpet size.

However, not all housewives had their carpets professionally

cleaned. For instance, the average cost for those living room carpets that were cleaned in the 20-to-40 percent coverage class was $8.84 per 100 square feet of carpet per year. However, only 44 percent of the living room carpets were professionally cleaned, so the average for all living room carpets was $3.86 per 100 square feet of carpet per year. In addition, since carpet made up only 30 percent of the living room area in that category, the cost per 100 square feet of room per year was only $1.16. The 44 percent of the living room carpets in the 20-to-40 percent category that were professionally cleaned compares to 73 percent in the 80-to-100 percent category. This would be expected because the larger carpet is more difficult for the housewife to clean by herself.

Also the fact that these values are given in dollars per year does not mean that every housewife has her carpet professionally cleaned every year. Many were professionally cleaned only once every 2 or 3 years, and were shampooed at home in between. As we noted before, many were never professionally cleaned, especially the smaller rugs.

Combined Minor Maintenance Cost

The combined minor maintenance cost to the tenant was obtained by adding the cost for minor maintenance materials to the cost for professional carpet cleaning (table 3).

Living Room.—The annual maintenance cost of hardwood floors in living rooms ($4.21 per 100 square feet) is about half that of either of the other two types of flooring; composition tile had a cost of $9.89 and wall-to-wall carpet (80-to-100-percent covered) averaged $8.27 per 100 square feet per year.

The maintenance costs for wall-to-wall carpet (80-to-100-percent cover) are the most reliable because approximately 50 percent of the tenants responding had floors in their living rooms that were over 80 percent covered with rug or carpet. The fewest observations were obtained in the low rug-coverage classes for composition tile, and the value of $9.89 for composition tile 0-to-20-percent covered is based on only 24 respondents. So less confidence can be placed in it than in the values for the other floor types and coverage classes.

Bedroom.—In the bedroom areas, the maintenance cost of hardwood floors ($3.24 per 100 square feet per year) was about half that of carpet and about 60 percent that of tile; wall-to-wall carpet averaged $6.38 and composition tile had a cost of $5.20.

Good confidence can be placed in all three of these values because the composition tile figure is based on 95 observations, the hardwood figure on 235 observations, and the wall-to-wall carpet figure on 267 observations. Although composition tile had fewer observations than the other two, 95 observations should still be enough to give a good estimate of the true average maintenance cost.

Dining Room.—The generally high maintenance costs for the dining room areas were probably caused by the family's frequent use of this area and the chance of spills which would require additional maintenance. Hardwood floors ($5.06 per 100 square feet per year) were the least expensive to maintain, the cost being about 75 percent that of composition tile and approximately 40 percent that of carpet. Composition tile required $6.90 per 100 square feet per year for maintenance and wall-to-wall carpet required an average of $12.07.

Reliability in these values should be good because the number of observations for composition tile, hardwood, and wall-to-wall carpet were 65, 149, and 169 respectively.

Single-Family-Home Owner

The floor costs for a single-family-home owner (table 4) are of course only estimates. We realize that a housewife in an apartment may not care for those floors as well as she might care for the floors in her own home. However, we believe that the relative differences in cost among the various floor types should remain about the same. There is no reason why she should treat one floor type better than another if she owned a home rather than rented, or vice versa. Consequently, all values in table 4 may be lower (or possibly even higher) than would actually occur in a single family home, but the relative ratings of the flooring types should not change.

Total Floor Costs

Hardwood floors have a distinct economic advantage when considering total floor costs. Under the conditions encountered in this study, a homeowner with a three-bedroom home (living room 15-by-20-foot, dining room 9-by-12-foot, and bedrooms 12-by-14-foot each, total for all rooms approximately 900 square feet) would save $2,111.50 over the period of a 25-year mortgage if he had hardwood floors instead of wall-to-wall carpet; he would save $586.25 if he had hardwood floors instead of composition tile. Cost savings such as these are worth considering when deciding which flooring material you should buy.

Maintenance Time

The average maintenance time spent on the different types of flooring varied considerably among materials. The high time values for composition tile were the result of frequent wet-mopping, buffing, and waxing. It seems that the housewife takes considerably more time and effort to keep composition tile at the appearance level she wants than she does for the other two types of flooring. Maintenance time for hardwood flooring and wall-to-wall carpet were approximately the same; carpet averaged about 5½ hours less per year.

Living Room.—Maintenance times for the living rooms were generally lower than for the other two room types. This should probably be expected because even though the living room is an area that requires a high appearance level, it is also more open and uncluttered and would be easier to clean.

The same time (14.1 hours/100 square feet/year) required to maintain hardwood floors 80-100 percent covered as wall-to-wall carpet would indicate that housewives do not treat carpet they own differently than carpet owned by the apartment owners.

Bedroom.—The bedrooms maintenance times were similar to those for the living rooms. In general, they were maintained less frequently than the living rooms, but the maintenance times required for each cleaning were about the same. Since bedrooms were only about half the size of the living rooms,

when maintenance time was compared on a per-square-foot basis, they came out about equal.

Here again, the 14.2 hours shown for hardwood floors 80-100 percent covered compared with the 16.3 hours shown for wall-to-wall carpet owned by the apartment building would indicate no bias against flooring material not owned by the tenant.

Dining Room.—In general, the maintenance times required were higher for the dining rooms than for either of the other two rooms. This should not be surprising. Dining rooms have an appearance level similar to that of living rooms and would require maintenance at least as frequently if not more frequently. Also, the dining rooms are small in comparison (averaging 108 square feet for this study) and generally quite congested, thereby making cleaning more difficult. When all these factors are combined, maintenance time on a square foot basis is bound to be higher. As an example, consider a dining room with 100 square feet and a living room with 300 square feet, each having the same frequency of maintenance and each taking 20 minutes per cleaning. On a square-foot basis, the maintenance time for the dining room would be three times as high as that for the living room.

Flooring Preferences

Housewives' flooring preferences (table 6) indicated that in general either the housewives selected and had the type of flooring they prefer, or that they had convinced themselves that the type of floor that they had is really what they would prefer if they were given a choice. Use of these data to predict national or regional preferences would not be valid because preferences seem to depend on what type of flooring material the respondents have at the time the survey is taken. For example, a survey of apartment dwellers in Los Angeles who have hardwood floors would probably indicate a preference for hardwood in that area. Yet Los Angeles has traditionally been predominantly a carpet area. However, the correlation between the type of flooring housewives have and the type they prefer could be an indicator of housewives' satisfaction with the various types of flooring.

Ease and Expense of Maintenance

The portion of the study dealing with housewives' opinions about the ease and expense of maintaining the different types of flooring was included for two reasons. First, we wanted to find out if there were predominant feelings among housewives that certain flooring materials were easiest or most difficult, cheapest or most expensive, to maintain. Second, we wanted to find out how closely these opinions were related to actual time and cost data determined by the study.

On the first point, we found that housewives apparently have no strong feelings about the ease and expense of maintaining the different floor coverings.

And on the second point, their opinions did not agree very well with the figures that they as a group provided. The combined categories of large rug on wood or tile and wall-to-wall carpet received about three-fourths of the votes for easiest to maintain. This does parallel our findings. However, this same combination received about 30 percent of the votes for most difficult, and this does not agree. Likewise, 40 percent of the housewives indicated that hardwood floors were the most difficult to maintain, yet those apparently took less than one-half as much time to maintain as composition tile. Almost 50 percent of the votes for least expensive to maintain went to the large rug or carpet categories, yet these were found to be the most expensive. And over 30 percent of the votes for most expensive went to hardwood, which was actually the least expensive.

CONCLUSION

Data from our study show that, regardless of the room type (living room, dining room, or bedroom), hardwood floors cost less than floors covered with composition tile or carpet. This is true both in terms of yearly cost and long-term cost. Hardwood floors also have a wear life much longer than that of other flooring materials.

Wall-to-wall carpet, although two to three times as expensive

as hardwood, has the advantage of requiring less time to maintain; but the difference is not large.

Composition tile is the cheapest floor material for an apartment owner to have in his building; but tenant maintenance costs are high, and tenant preferences indicate that tile is not as well received as hardwood, which is only slightly higher in total cost. Wall-to-wall carpet is by far the most expensive to the apartment building owner, although it is well received by the tenants.

Single-family-home owners could save more than $2000 over the period of their mortgage by having hardwood floors throughout their home instead of wall-to-wall carpeting. Likewise, they could save more than $580 by having hardwood instead of composition tile.

Overall, in yearly cost, long-term cost, wear life, maintenance time, and preference, hardwood floors appear to be the most practical for the single-family-home owner, the apartment tenant, and the apartment building owner.

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■

APPENDIX I

Table 8. — Number of observations in each cell

Type of flooring	Rug coverage, in percent					
	0-20	20-40	40-60	60-80	80-100	Total
LIVING ROOM						
Composition tile	24	9	39	32	105	209
Hardwood flooring	60	37	88	86	185	456
Carpet (wall-to-wall)	—	—	—	—	95	95
Total	—	—	—	—	—	760
BEDROOM						
Composition tile	95	4	12	25	67	203
Hardwood flooring	235	19	32	71	117	474
Carpet (wall-to-wall)	—	—	—	—	83	83
Total	330	23	44	96	267	760
DINING ROOM						
Composition tile	65	0	3	1	45	114
Hardwood flooring	149	16	29	27	51	272
Carpet (wall-to-wall)	—	—	—	—	73	73
Total	214	16	32	28	169	459

Table 9. — Range[1] of average times spent for maintenance, by type of flooring and rug-coverage area

[In hour/100 square feet/year]

Floor type	Range	Percent of rug coverage				
		0-20	20-40	40-60	60-80	80-10
		LIVING ROOM				
Composition tile	Low	17.6	24.3	33.5	22.6	17.8
	Mean	44.4	34.0	41.6	52.1	21.1
	High	74.4	38.7	49.8	68.3	24.9
Hardwood flooring	Low	8.7	13.6	20.4	16.7	9.0
	Mean	21.8	17.9	34.4	28.2	14.1
	High	25.1	38.5	49.2	38.0	14.7
Carpet (wall-to-wall)	Low	—	—	—	—	10.4
	Mean	—	—	—	—	14.1
	High	—	—	—	—	14.6
		BEDROOM				
Composition tile	Low	14.7	—	21.3	22.1	13.6
	Mean	37.2	(*)	31.5	34.0	21.2
	High	62.4	—	36.1	48.0	40.7
Hardwood flooring	Low	15.6	21.2	16.4	24.0	10.5
	Mean	23.9	30.7	17.8	41.9	14.2
	High	30.2	39.2	18.8	52.0	18.1
Carpet (wall-to-wall)	Low	—	—	—	—	8.8
	Mean	—	—	—	—	16.3
	High	—	—	—	—	17.6
		DINING ROOM				
Composition tile	Low	36.3	—	—	—	25.1
	Mean	102.0	(*)	(*)	(*)	27.1
	High	241.2	—	—	—	32.0
Hardwood flooring	Low	22.3	14.1	13.0	25.8	14.3
	Mean	36.4	32.3	22.3	52.8	23.5
	High	44.7	48.9	32.7	122.2	28.1
Carpet (wall-to-wall)	Low	—	—	—	—	21.4
	Mean	—	—	—	—	36.1
	High	—	—	—	—	38.4

[1] Range of average regional values

* Insufficient data

APPENDIX II

Basic Assumptions in Conducting the Study

The main assumption in this study was that the housewife would provide the most objective information about maintenance procedures used, materials required, equipment needed, and when the floors were in need of maintenance to keep them at an acceptable appearance level. If it were possible to conduct the study under controlled conditions, we would have had to define these criteria, and therefore they would have been subjective and subject to bias. Although we eliminated the subjectiveness, we did so at the expense of greater variability. By using housewives' opinions, we did not get the smooth curves obtainable through controlled studies.

The only criteria we specified was a standard of minimum maintenance. We insisted that some method of removing the dust must be performed, that smooth-surface flooring materials must be waxed, and that carpets must be spot-cleaned. How the housewives performed these duties or how often was not specified. In theory then, a housewife may wax smooth-surface floors once a year and never wet-mop, buff, or remove wax buildup. Likewise, she may spot-clean her carpets and never need to shampoo or lift the pile. However, the study showed that most housewives were better homemakers than that.

Another assumption, discussed in the text, was that the apartment housewives would provide maintenance information indicative of that obtained from housewives in a single-family home. Although it is possible that housewives in an apartment do not take as good care of their floors as housewives in a single-family home, there is no reason to believe they would take better care of one flooring material than another. Therefore the relative differences between flooring materials would remain the same.

Another assumption was that average minor maintenance costs could be determined by combining (1) the information from the housewives on how frequently they performed their various maintenance functions and the types of materials they used with (2) the information from the materials manufacturers on the suggested retail prices of the various materials and the coverage areas they expected from them.

The major categories of waxes and wax removers used in calculating minor maintenance costs on smooth-surface floors included: (1) solvent-type waxes (liquid, buffable); (2) solvent-type waxes (paste, buffable, including paste wax emulsions); (3) wax emulsions (liquid self-polishing, cleaning, or non-cleaning); and (4) commercial wax removers. The major categories of shampoos and cleaners used for carpets and rugs included: (1) liquid shampoos; (2) dry rug cleaners; (3) detergents and other cleaners, which are mixed with water; and (4) commercial spot cleaners.

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A SURVEY OF PLANTS IN GUJARAT, INDIA, FOR ALKALOIDS, SAPONINS, AND TANNINS

by Basalingappa L. Hungund and
Chandravadan H. Pathak

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A SURVEY OF PLANTS IN GUJARAT, INDIA, FOR ALKALOIDS, SAPONINS, AND TANNINS

A FLORISTIC and phytochemical survey of forests in Gujarat State, India, is being undertaken to identify sources of alkaloids, saponins, and tannins. This note is a report on the results of screening 105 plant species collected from that region.

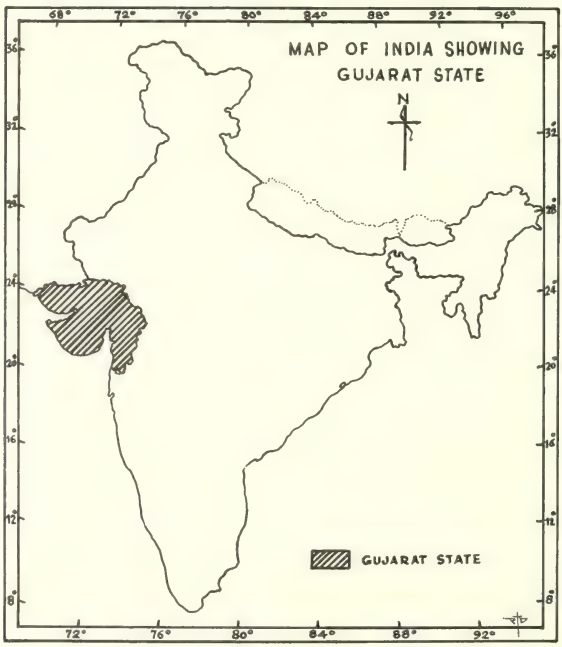
Methods

Plants were collected from forest regions of Gujarat State. The plant parts were air-dried and then separated and dried to a constant weight at 60°C.

About 5 gms. of the dry crushed plant material were divided into two parts. One part was treated with liquor ammonia for 40 to 60 minutes and then extracted in ethanol for 48 hours at 30°C. The ethanol extract was distilled under vacuum, transferred to a china clay dish, and evaporated to dryness. The dried extract was treated with dilute H_2SO_4. The acid extract was centrifuged and tested for alkaloids with Dragendroff's *(4)* and Mayers and Wagners *(1)* reagents.

The other portion of the plant material was extracted in boiled water. After cooling, half of the extract was shaken vigorously to froth and then was allowed to stand for 15 to 20 minutes and was classified for saponin contents. (No froth = negative; froth less than 1 cm. high = weakly positive; froth 1 cm. to 2 cm. high = positive; and froth greater than 2 cm. high = strongly positive *(2)*.) Only the materials classed as positive or strongly positive were considered in the study.

The water extract was also used for screening with gelatin salt solution and iron alum reagents *(3)* to test for presence of tannins.



Results

Of the 105 plant species tested, 86 were found to be alkaloid-bearing, 34 showed presence of saponins, and 44 showed presence of tannins (table 1).

Table 1.—*Summary results of 105 plant species tested for presence of alkaloids, saponins, and tannins*

[+ indicates positive reaction]

Plant parts are abbreviated as follows: B = bark, F = flowers, Fr = fruit, FrW = fruit wall, Inf = inflorescence, L = leaves, P = pods, R = roots, S = stem, Sd = seeds, SP = small plant, YB = young branch.

No.	Plant name	Plant parts	Test for —		
			Alkaloids	Saponins	Tannins
	DILLENIACEAE				
1.	*Dillenia pentagyna* Roxb.	S	—	—	+
		L	—	—	—
	ANONACEAE				
2.	*Miliusa tomentosa* (Roxb.) Sinclair	S	+	—	+
		L	+	—	+
		Fr	+	+	+
	MENISPERMACEAE				
3.	*Cissampelos pareira* Linn.	S	+	—	—
		L	+	—	—
4.	*Cocculus hirsutus* (Linn.) Diels.	S	+	—	—
		L	+	—	—
5.	*Tinospora cordifolia* Miers.	S	+	—	—
		R	+	—	—
	PAPAVERACEAE				
6.	*Argemone mexicana* Linn.	S	+	—	—
		L	+	—	—
		R	+	—	—
	CAPPARIDACEAE				
7.	*Cleome simplicifolia* H.f. & T.	S	+	—	+
		L	+	—	+
8.	*Crataeva nurvala* Buch.-Ham.	S	+	—	—
		L	+	—	—
	TAMARICACEAE				
9.	*Tamarix ericoides* Rottl.	YB	—	—	+
		F	—	—	+
	BOMBACACEAE				
10.	*Adansonia digitata* Linn.	Fr	+	+	—
		Sd	—	+	—
11.	*Bombax ceiba* Linn.	L	+	—	—
	STERCULIACEAE				
12.	*Sterculia foetida* Linn.	Fr	—	—	+
13.	*Sterculia urens* Roxb.	FrW	+	—	—
		B	—	—	—
	TILIACEAE				
14.	*Corchorus olitorius* Linn.	S	+	+	—
		L	+	+	—
		Fr	+	+	—

CONTINUED

Table 1.—Continued

No.	Plant name	Plant parts	Test for — Alkaloids	Saponins	Tannins
15.	*Corchorus trilocularis* Linn.	S	+	+	—
		L	+	+	—
		Fr	—	+	—
	MALPIGHIACEAE				
16.	*Hiptage benghalensis* (L.) Kurz.	S	—	+	—
		L	—	+	+
		F	—	+	+
	OXALIDACEAE				
17.	*Biophytum sensitium* (Linn.) DC.	SP	+	—	—
	BURSERACEAE				
18	*Boswellia serrata* Roxb.	S	—	—	+
		B	—	—	+
	CELASTRACEAE				
19.	*Celastrus panticulatus* Willd.	L	—	—	—
		Fr	—	—	—
20.	*Maytenus emarginatus* (Willd.) Ding Hou	S	—	—	+
		L	+	—	+
		F	—	+	—
	SAPINDACEAE				
21.	*Cardiospermum halicacabum* Linn.	S	+	—	—
		L	+	—	—
		Sd	+	—	—
22.	*Sapindus emarginatus* Vahl	S	—	+	—
		L	—	+	+
	PAPILIONACEAE				
23.	*Clitoria biflora* Dalz.	S	—	+	—
		L	+	+	—
24.	*Crotalaria retusa* Linn.	S	+	+	—
		L	+	—	—
		Fr	+	+	—
25.	*Dalbergia latifolia* Roxb.	Fr	+	—	+
26.	*Dalbergia sisso* Roxb.	S	+	—	—
		L	+	—	—
		Fr	+	—	—
27.	*Indigofera oblongifolia* Forsk.	S	+	+	—
		L	+	+	—
28.	*Pongamia pinnata* (L.) Pierre	B	—	—	—
29.	*Pterocarpus marsupium* Roxb.	B	—	+	+
		L	—	+	—
		FrW	+	—	—
		Sd	+	—	—
30.	*Tephrosia hamiltonii* J. R. Drumm.	S	+	—	—
		R	+	+	+

CONTINUED

Table 1.—Continued

No.	Plant name	Plant parts	Test for — Alkaloids	Saponins	Tannins
	CAESALPINIACEAE				
31.	*Cassia auriculata* Linn.	S	—	—	+
		L	—	—	+
		F	—	—	+
		Fr.	—	—	+
32.	*Cassia fistula* Linn.	Sd	—	+	—
		FrW	+	+	+
33.	*Cassia italica* (Mill.) Lamk.	S	+	—	—
		L	+	—	—
		F	+	—	—
		Fr	+	—	—
34.	*Cassia occidentalis* Linn.	S	+	+	+
		L	+	—	—
		R	+	+	—
35.	*Cassia sophera* Linn.	S	+	—	—
		L	+	—	—
36.	*Caesalpinia crista* Linn.	Fr	+	—	+
37.	*Parkinsonia aculeata* Linn.	S	+	+	—
		L	+	—	—
		F	+	—	—
		Sd	+	—	—
		P	+	+	+
	MIMOSACEAE				
38.	*Acacia chundra* (Roxb.) Willd.	Sd	—	+	—
39.	*Acacia intsia* Willd.	S	—	—	+
		P	—	—	+
		Sr	+	—	—
40.	*Acacia pennata* Willd.	P	+	—	+
41.	*Albizzia procera* (Roxb.) Benth.	L	—	—	+
		P	—	—	+
42.	*Prosopis spicigera* Linn.	S	+	+	+
		L	+	+	+
		Fr	—	+	+
	COMBRETACEAE				
43.	*Anogeissus latifolia* Wall. ex Beddome	S	—	—	+
		L	—	—	+
		Fr	+	—	+
44.	*Anogeissus pendula* Edgew.	S	+	—	+
		L	+	—	+
		Fr	+	—	+
45.	*Calycopteria floribunda* Lam.	S	—	—	+
		L	+	—	+
		F	—	+	—

CONTINUED

Table 1.—Continued

No.	Plant name	Plant parts	Test for — Alkaloids	Saponins	Tannins
46.	*Combretum ovalifolium* Roxb.	Fr	+	—	+
47.	*Terminalia arjuna* (Roxb. ex DC.) Wt. & Arn.	Fr	—	—	+
48.	*Terminalia bellirica* (Gaertan.) Roxb.	Fr	+	—	+
49.	*Terminalia crenulata* Roth.	Fr	+	—	+
	LYTHRACEAE				
50.	*Lagerstroemia lanceolata* Roxb.	S	+	—	+
		B	+	—	+
		Fr	—	—	—
51.	*Woodfordia fruticosa* (L.) Kurz	S	—	+	+
		L	—	+	+
		F	+	+	+
	FICOIDACEAE				
52.	*Sesunium portulacastrum* Linn.	S	+	+	+
		L	+	+	+
53.	*Trianthema hydaspica* Edgew.	S	+	—	—
		L	+	—	—
		F	+	—	—
	UMBELLIFERAE				
54.	*Pimpinella adscendens* Dalz.	S	—	—	—
		Fr	+	—	—
	RUBIACEAE				
55.	*Adina cordifolia* Hook. f.	S	+	+	+
		F	—	—	+
		Fr	+	—	+
56.	*Borreria articularis* (L.f.) F.N. Will	S	—	—	+
		L	—	—	+
		R	—	—	—
57.	*Morinda tomentosa* Heyne ex Roth.	S	+	—	—
		L	+	+	—
	COMPOSITAE				
58.	*Cyathocline purpurea* (Don.) O. Kuntze	S	+	—	+
		L	+	—	+
		F	+	—	+
59.	*Elephantopus scaber* Linn.	S	—	+	—
		R	+	—	—
	PLUMBAGINACEAE				
60.	*Plumbago zeylanica* Linn.	S	+	—	+
61.	*Vogelia indica* Gibs.	S	+	—	+
		L	+	—	+
	APOCYNACEAE				
62.	*Holarrhena antidysentierica* Wall.	L	+	—	+

CONTINUED

Table 1.—Continued

No.	Plant name	Plant parts	Test for — Alkaloids	Saponins	Tannins
63.	*Rauwolfia tetraphylla* Linn.	S	+	—	—
		L	+	—	—
		Sd	+	—	—
	ASCLEPIADACEAE				
64.	*Hemidesmus indicus* R. Br.	S	+	—	—
		L	—	—	+
		R	+	—	—
	GENTIANACEAE				
65.	*Canscora diffusa* R. Br.	S	—	—	—
		L	+	—	—
66.	*Enicostemma hyssopifolium* (Willd.) Verd.	S	+	—	—
		L	+	—	—
	BORAGINACEAE				
67.	*Heliotropium scabrum* Retz.	S	+	—	—
		L	+	+	—
		F	+	+	—
	CONVOLVULACEAE				
68.	*Convolvulus microphyllus* Sieb.ex Spreng	S	+	—	—
		L	+	—	—
		F	+	—	—
69.	*Cressa cretica* Linn.	S	+	—	—
		L	—	—	—
70.	*Evolvulus alsinoides* Linn.	S	+	—	—
		L	+	—	—
		R	+	—	—
71.	*Ipomea digitata* Linn.	S	+	—	—
		L	+	—	—
		F	+	—	—
72.	*Merremia tridentata* (Linn.) Hall. f.	S	+	—	+
	SOLANACEAE				
73.	*Withania somnifera* (L.) Dunal	S	+	—	—
		L	+	—	—
		R	+	—	—
	SCROPHULARIACEAE				
74.	*Lindenbergia muraria* (Rob.) P. Bruehl.	L	—	+	—
		F	—	+	—
	BIGNONIACEAE				
75.	*Oroxylum indicum* Vent.	B	—	—	—
		L	+	—	—
		Sd	+	+	—
		P	+	+	—
76.	*Tecomella undulata* Seem.	S	+	+	—
		L	+	+	—

CONTINUED

Table 1.—Continued

No.	Plant name	Plant parts	Test for — Alkaloids	Saponins	Tannins
	ACANTHACEAE				
77.	*Adhatoda vasica* Nees	S	+	—	—
		L	+	—	—
		F	+	—	—
78.	*Andrographis echioides* Nees	S	+	—	—
		L	+	—	—
79.	*Barleria prionitis* Linn.	S	+	—	—
		L	+	—	—
80.	*Bremekampia verticillata* (Roxb.) Sreem.	S	+	—	—
		L	+	—	—
		F	+	—	—
81.	*Elytraria acaulis* (Linn.) Linades	L	+	—	—
		F	+	+	—
82.	*Eranthemum rosaeum* (Vahl) R. Br.	S	—	—	—
		R	+	+	—
83.	*Ruellia tuberosa* L.	S	—	—	—
		L	—	—	—
	VERBENACEAE				
84.	*Clerodendron phlomidis* Linn. f.	S	+	—	—
		L	+	—	—
		F	+	—	—
85.	*Nyctanthes arbor-tristis* Linn.	S	+	—	—
		L	+	+	—
		P	+	—	—
86.	*Tectona grandis* Linn.	S	+	—	—
87.	*Vitex negundo* Linn.	L	—	—	—
	LABIATAE				
88.	*Anisomeles indica* (Linn.) O. Kuntze	S	+	—	—
		L	+	—	—
		F	+	—	—
		Inf	+	—	—
	NYCTAGINACEAE				
89.	*Boerhavia diffusa* Linn.	S	+	—	—
		L	+	—	—
		R	+	—	—
	AMARANTHACEAE				
90.	*Achyranthes aspera* Linn.	S	+	—	—
	var. *porphyristachya* Hook f.	L	+	—	—
		R	+	—	—
		Sd	+	+	—

CONTINUED

Table 1.—Continued

No.	Plant name	Plant parts	Test for —		
			Alka-loids	Sapo-nins	Tan-nins
	LORANTHACEAE				
91.	*Dendrophthoe falcata* (L.f.) Ettings	S	—	+	+
		L	+	—	+
		F	—	—	+
92.	*Viscum nepalense* Spreng.	S	+	—	—
		Fr	—	—	—
	EUPHORBIACEAE				
93.	*Baliospermum montanum* (Willd.) Muell.	S	+	—	—
		L	+	—	—
		R	+	—	—
		Fr	+	+	—
94.	*Bridelia squamosa* (Mueel. Arg.) Germ.	L	+	—	—
95.	*Dalechampia scandens* Linn.	S	—	+	—
	var. *cordofana* (Hochst.) Muell. Arg.	L	+	+	+
96.	*Emblica officinalis* Gaertn.	L	—	—	+
	ULMACEAE				
97.	*Trema orientalis* (Linn.) Blume	S	+	—	—
		L	+	—	—
	URTICACEAE				
98.	*Ficus bengalensis* Linn.	S	—	—	+
		L	+	—	—
		Fr	—	—	+
	MUSACEAE				
99.	*Musa rosacea* Jacq.	Inf	—	—	+
	DIOSCOREACEAE				
100.	*Dioscorea bulbifera* Linn.	S	+	—	—
		Fr	+	—	—
	LILIACEAE				
101.	*Asparagus racemosus* Willd. var. *javanica* Baker	R	+	—	—
102.	*Chlorophytum tuberosum* Baker	R	—	—	—
103.	*Gloriosa superba* Linn.	S	—	—	—
		L	+	—	—
	GRAMINEAE				
104.	*Cymbopogon martinii* (Roxb.) Wats	S	+	—	—
	POLYPODIACEAE				
105.	*Actiniopteris australis* (L.f.) Link.	L	+	—	—
		R	+	—	—

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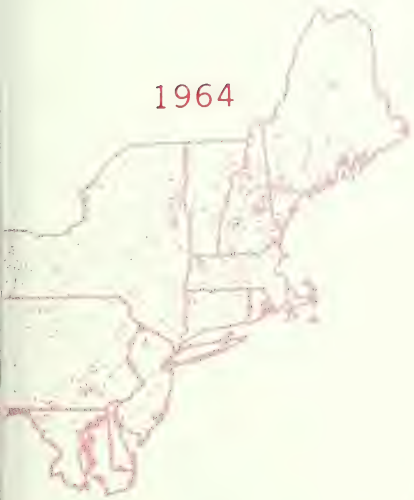
Growth of the CAMPING MARKET in the Northeast



by George H. Moeller

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Growth of the CAMPING MARKET in the Northeast

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ALMOST LIKE an atomic explosion, the number of commercial campgrounds in the Northeast mushroomed 800 percent between 1961 and 1967. During this same period, the number of public campgrounds increased by only 40 percent.

The pattern of commercial and public campground growth in the Northeast was studied over a 6-year period to find how such growth may relate to geographic features, population distribution, and existing campground locations. This information provides insight into future campground-market growth trends, and may be useful in developing recreation programs and policies.

CAMPING MARKET GROWTH

During a span of 6 years, the camping market shifted from dominance by the public sector to dominance by the commercial sector, in terms of campground numbers. In 1961, public campgrounds outnumbered commercial campgrounds 273 to 160 — a ratio of almost 2 to 1. By 1967, the market composition had reversed to a ratio of 4 to 1 in favor of commercial campgrounds (table 1).

Table 1.—*Campground market growth in the Northeastern States, 1961-67*
[Number of campgrounds]

State	1961		1964		1967	
	Commercial	Public[1]	Commercial	Public[1]	Commercial	Public[1]
nnecticut	0	20	8	21	25	22
laware	0	2	5	2	12	4
ine	66	18	136	23	206	26
ssachusetts	10	24	52	29	80	34
ryland	3	15	16	16	40	26
w Hampshire	40	30	115	33	183	35
w Jersey	8	9	40	9	88	18
w York	16	85	297	89	421	105
nsylvania	7	44	203	55	279	64
ode Island	3	1	7	2	17	5
rmont	7	25	39	30	77	38
Total	160	273	918	309	1,428	377

ource: Yearly summaries were compiled from sources identified in figures 1, 2, and 3.
Includes State, Federal (National Park Service, USDA Forest Service, Corps of Engineers), and mmunity or town campgrounds.

In 1961, public facilities were concentrated in heavily forested regions such as the Adirondack Preserve in New York State and the National and State forests in Pennsylvania, Vermont, and New Hampshire. Although commercial campgrounds were abundant in the White Mountains of New Hampshire, and in central and coastal Maine, they were sparsely scattered throughout the remainder of the Northeast (fig. 1).

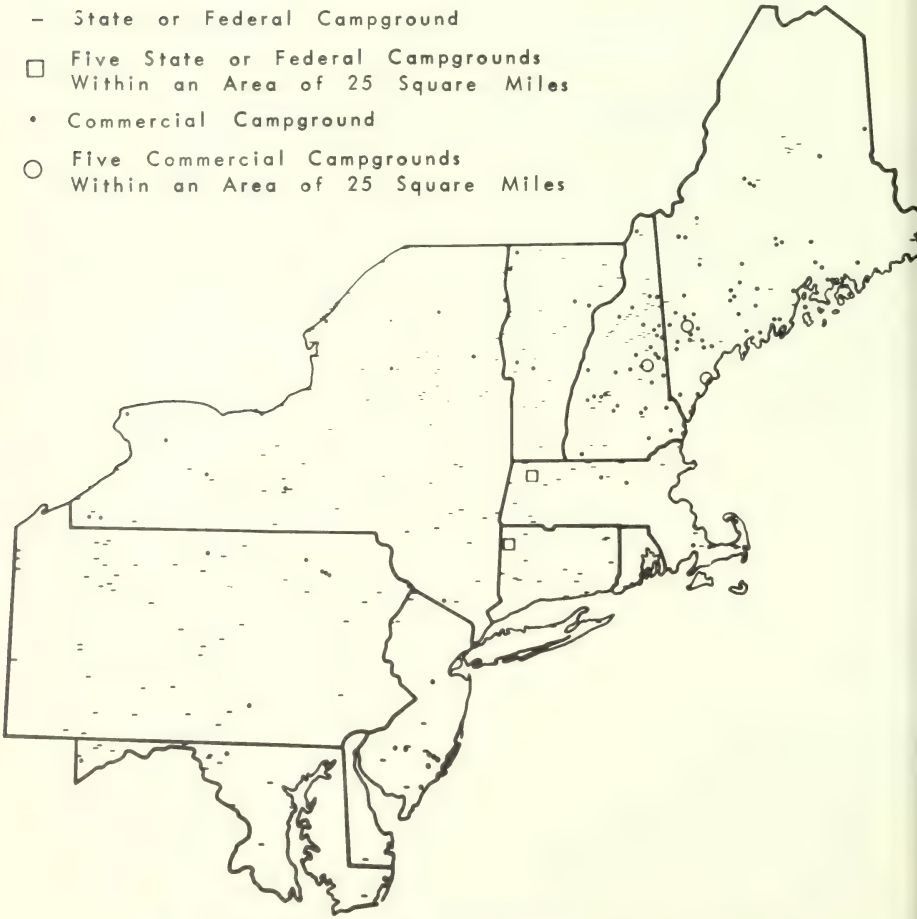

– State or Federal Campground
□ Five State or Federal Campgrounds Within an Area of 25 Square Miles
• Commercial Campground
○ Five Commercial Campgrounds Within an Area of 25 Square Miles

Figure 1.—Campgrounds of the Northeast, 1961. Compiled from *Private Campgrounds U.S.A.;* Hammond *Guide to Campsites,* 1962; State Campground Association brochures; (ORRRC) *Public Outdoor Recreation Areas 1960;* Nat. Park Serv. *Parks for America,* 1964; correspondence with state and federal recreation agencies.

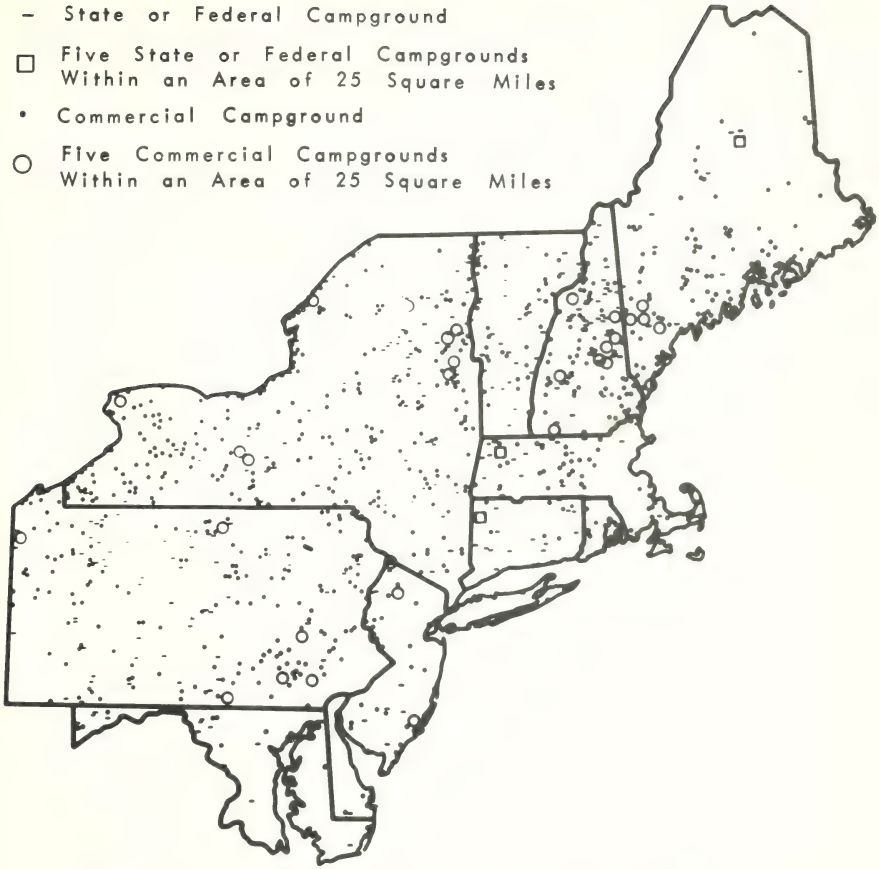

– State or Federal Campground
□ Five State or Federal Campgrounds Within an Area of 25 Square Miles
• Commercial Campground
○ Five Commercial Campgrounds Within an Area of 25 Square Miles

Figure 2.—Campgrounds of the Northeast, 1964. Compiled from *Private Campgrounds U.S.A.* and *Camping Maps U.S.A.*, 1965; Bureau Outdoor Recreation *Public Sector Inventory; Family Campground Directory for New York State, 1965;* Campground Association directories 1964; Corps of Engineers recreation directories; correspondence with state and federal recreation agencies.

By 1964, commercial campgrounds outnumbered public campgrounds 918 to 309 (fig. 2), and by 1967, commercial campgrounds outnumbered public campgrounds 1428 to 377 (fig. 3). Although commercial campground growth was scattered throughout most of the Northeast, major concentrations or clusters occurred around existing public recreation lands, resort areas, seashores, and lake areas.

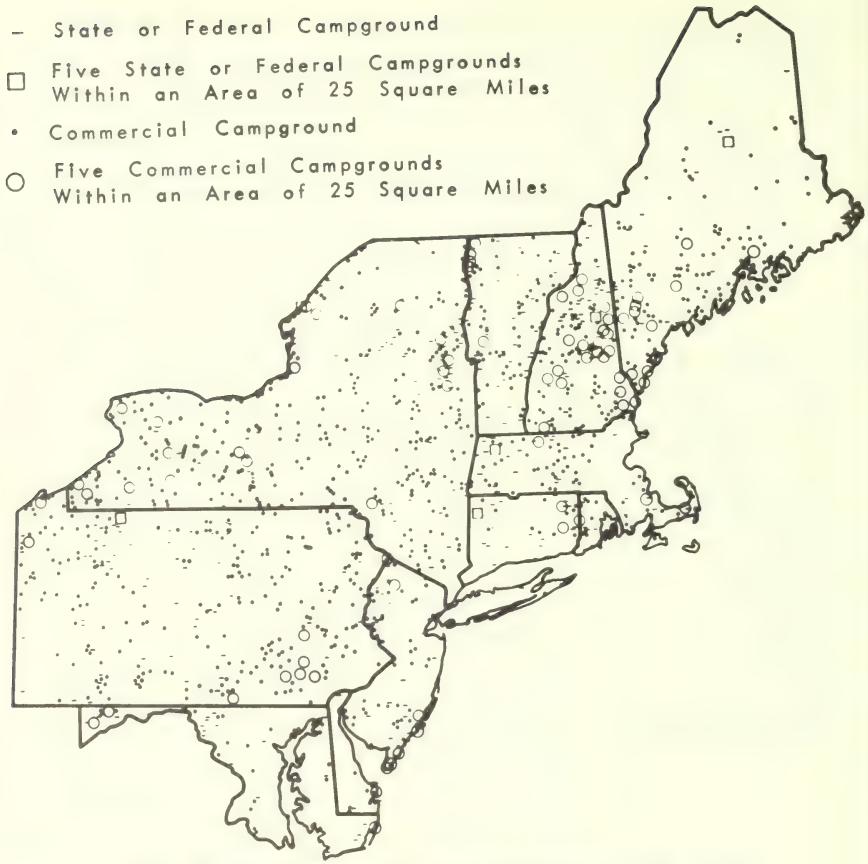

– State or Federal Campground
□ Five State or Federal Campgrounds Within an Area of 25 Square Miles
• Commercial Campground
○ Five Commercial Campgrounds Within an Area of 25 Square Miles

Figure 3.—Campgrounds of the Northeast, 1967. Compiled from *Private Campgrounds U.S.A.*, 1968; *Rand McNally Guidebook to Campgrounds*, 1968; *Woodall's Camping Directory*, 1968; correspondence with state and federal recreation agencies.

Statistical procedures described by Crow *et al. (1960)* were used to determine if campgrounds were distributed randomly in the Northeast. A transparent overlay was used to construct a frequency distribution of the number of commercial and public campgrounds falling within 20-mile grid squares. The frequency distribution obtained was compared, using a Chi-square test, to the distribution that would be expected if campgrounds were randomly distributed. Neither commercial nor public campgrounds were found to be distributed randomly throughout the Northeast

in 1961, 1964, or 1967. (Randomness was rejected at the 0.99 probability level.) Because campgrounds were not distributed randomly, possible relationships between selected geographic characteristics and campground location patterns were examined.

PROCEDURE

Each geographic characteristic considered in this study was divided into several zones. A *zone* was a particular area of land in the Northeast delineated according to: (1) proximity to major water bodies; (2) amount of open space; (3) density of forest cover; (4) topography; (5) distance from major metropolitan centers; (6) county population density; or (7) campground clustering.

The relationships between campground location and selected geographic characteristics were examined according to the following rationale: if campgrounds in the Northeast are evenly distributed, the proportion of campgrounds in a given zone should be approximately equal to the proportion of the land area in the zone. The same reasoning applies to the increase in the number of campgrounds over time, or campground market growth, within a particular zone. If campground market growth was evenly distributed throughout the Northeast, the *expected* proportion of campground growth that occurred in a zone should be approximately equal to the proportion of the total land area in that zone. The *actual* campground market growth was measured as the proportion of total campground growth in the Northeast that occurred in a particular zone.

The magnitude of the difference between the *expected* and *actual* campground growth within a given zone was used as an indication of the relationship between campground growth and a zone's characteristic. If actual campground market growth was less than expected growth, a zone's characteristic was assumed to be negatively related to campground growth. If actual and expected growth percent were approximately equal, the zone's characteristic was assumed to be unassociated with campground market development. Finally, if actual campground growth was greater than expected growth, the characteristic used to define a

zone was assumed to be associated with campground market growth.

MARKET GROWTH AND GEOGRAPHIC FEATURES

Differences of 5 percent or more between actual and expected campground growth percents were used to report important associations between a zone's characteristics and campground growth. A difference as small as 5 percent may not seem important; however, in a regional study incorporating a large area where the total population is represented (all campgrounds in the Northeast), a difference of 5 percent may represent a large number of campgrounds. The significance of percent comparisons will vary with the number of observations used in calculating percents. Therefore, in interpreting the significance of results, the reader should keep in mind that campground market growth —the total 6-year change in the number of commercial and public campgrounds from 1961 to 1967—was 1,268 commercial campgrounds and 104 public campgrounds.

Distance from Major Water Bodies

The importance of water to the camping experience has been well documented. However, the role that water plays in locating campgrounds has not been examined. A 1965 USDA water resources map was used to define major bodies of water. The base map was used to construct a system of 5-mile proximity-to-water zones adjacent to major water resources in the Northeast. Proximity-to-water zones were used to compare the percent of actual commercial and public campground growth occurring in a zone with the percent of the Northeastern study area contained in the zone.

Results of a comparison of the actual and expected growth percents within distance from water zones underscores the close association between campground market growth and distance from major water resources. The area contained within the 0 to 5-mile proximity-to-water zone represented 37.2 percent of the total land area in the Northeast, but 59.3 percent of commercial

and 62.5 percent of public campground growth occurred in the zone (table 2). Therefore, growth in the commercial camping market was 22.1 percent greater than expected, and growth in the public sector was 25.3 percent greater than would be expected if campground market growth was not associated with proximity-to-water.

Percent of commercial and public campground growth was approximately equal to the percent of land area contained in all zones greater than 10 miles from major water bodies. However, actual commercial and public campground growth were, respectively, 10.5 percent and 20.1 percent less than the expected growth in the 5- to 10-mile zone (table 2).

Table 2.—*Campground market growth in relation to proximity to major water bodies, 1961-67*

Proximity-to-water zone (miles)	Expected campground market growth[1]	Actual campground market growth			
		Type of campground	Year	Campgrounds in zone	Proportion of total growth within zone[2]
	Percent			*No.*	*Percent*
0-5	37.2	Commercial	1961	122	59.3
			1967	873	
		Public	1961	145	62.5
			1967	210	
5-10	23.0	Commercial	1961	12	12.5
			1967	171	
		Public	1961	40	2.9
			1967	43	
10-20	22.6	Commercial	1961	12	14.5
			1967	196	
		Public	1961	40	20.2
			1967	61	
20+	17.2	Commercial	1961	14	13.7
			1967	188	
		Public	1961	48	14.4
			1967	64	

[1]Expected campground market growth = percent of the total Northeastern study area contained in each proximity-to-water zone.

[2]Proportion of total growth = $\frac{\text{Commercial (or public) campground growth in the zone (1961-67)}}{\text{Total commercial (or public) campground growth in the Northeast (1961-67)}}$.

Empty Land Areas

Categories of empty land areas in the Northeast were also related to the growth of the camping market. A map prepared by Klimm *(1954)* was used to divide the study area into empty-area zones (fig. 4). Klimm's map was constructed by grouping land areas according to patterns of empty-area tracts. An empty-area tract was defined as a land unit having a minimum dimension of 1 mile, that was uninhabited, was not used for agriculture, and contained no occupied structure. Empty-area patterns were

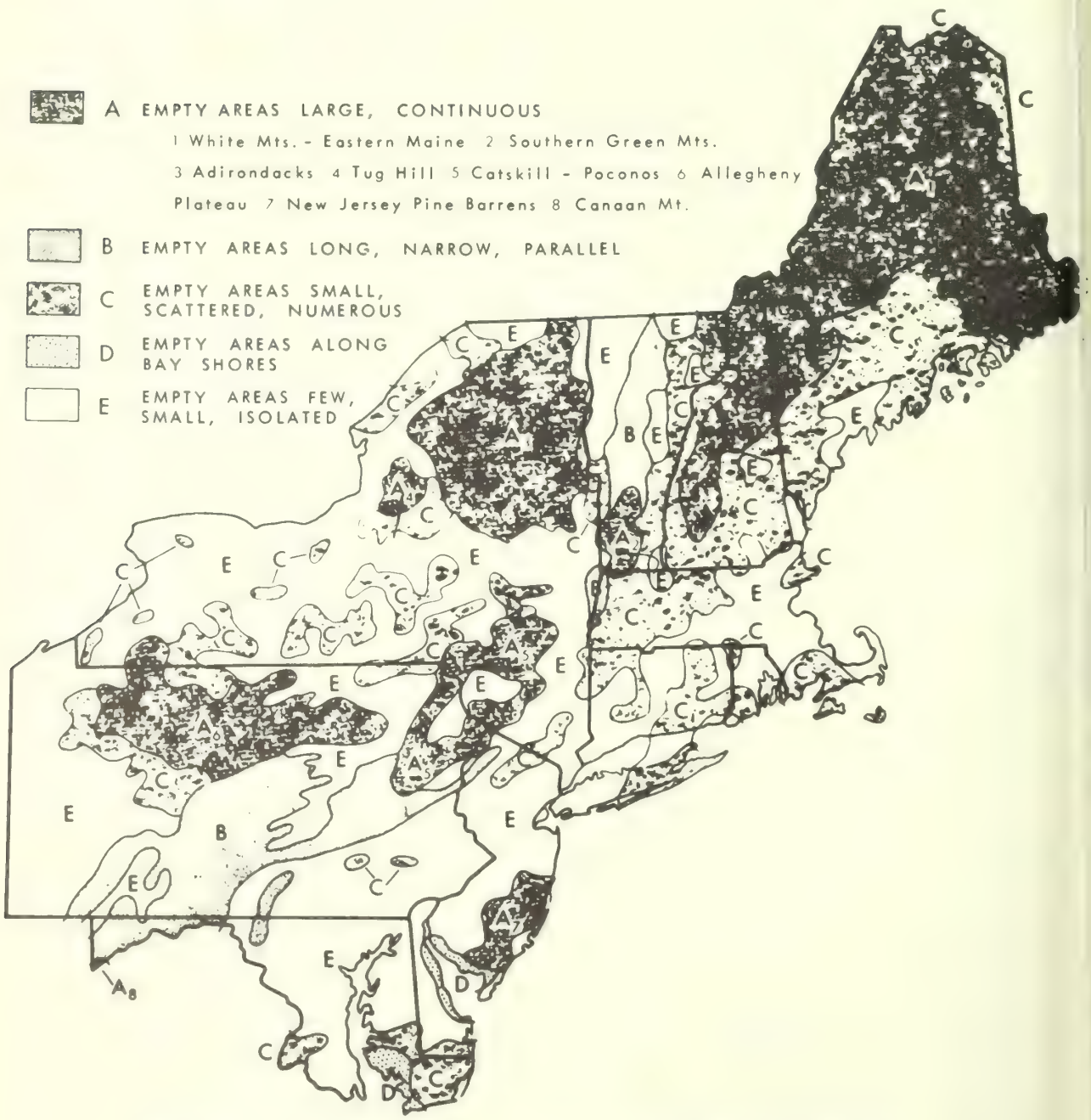

A EMPTY AREAS LARGE, CONTINUOUS
1 White Mts. - Eastern Maine 2 Southern Green Mts.
3 Adirondacks 4 Tug Hill 5 Catskill - Poconos 6 Allegheny
Plateau 7 New Jersey Pine Barrens 8 Canaan Mt.
B EMPTY AREAS LONG, NARROW, PARALLEL
C EMPTY AREAS SMALL, SCATTERED, NUMEROUS
D EMPTY AREAS ALONG BAY SHORES
E EMPTY AREAS FEW, SMALL, ISOLATED

Figure 4.—Categories of empty areas in the Northeastern United States. Source: Klimm, Lester E., 1954: The empty areas of the Northeastern United States; Geog. Rev. 44 (3): 325-345 (reproduced with permission of the publisher).

Table 3.—*Campground market growth in relation to empty areas, 1961-67*

Empty-area zone	Expected campground market growth[1]	Actual campground market growth			
		Type of campground	Year	Campgrounds in zone	Proportion of total growth within zone[2]
	Percent			*No.*	*Percent*
Large-continuous	30.9	Commercial	1961	49	22.0
			1967	328	
		Public	1961	103	37.5
			1967	142	
Long-narrow-parallel	7.4	Commercial	1961	8	6.0
			1967	84	
		Public	1961	28	7.7
			1967	36	
Small-scattered-numerous	20.5	Commercial	1961	59	25.1
			1967	378	
		Public	1961	70	21.2
			1967	92	
Along-bay-shores	0.1	Commercial	1961	0	0.6
			1967	7	
		Public	1961	0	0.9
			1967	1	
Few-small-isolated	41.1	Commercial	1961	44	46.3
			1967	631	
		Public	1961	72	32.7
			1967	106	

[1]Expected campground market growth = percent of the total Northeastern study area contained in each empty area zone.

[2]Proportion of total growth = $\frac{\text{Commercial (or public) campground growth in the zone (1961-67)}}{\text{Total commercial (or public) campground growth in the Northeast (1961-67).}}$

determined by size, shape, texture, and frequency of empty-area tracts. Empty-area patterns were grouped into five broad empty-area zones. Klimm's map was used to compare actual campground market growth occurring within each empty-area category with the land area contained in each category (table 3).

The percent of actual commercial and public campground growth was approximately equal to expected growth for three of the empty-area zones: long-narrow-parallel; small-scattered-

numerous; and empty areas along bay shores—zones B, C, and D, respectively (fig. 4).

Actual campground growth and expected growth were unequal and showed opposite growth patterns for commercial and public campgrounds in the two remaining empty-area zones: large continuous and few-small-isolated—zones A and E, respectively fig. 4.

Though 30.9 percent of the land area in the Northeast is contained in the large-continuous empty-area zone, only 22.0 percent of the commercial growth occurred there; but 37.5 percent of the public growth took place in that zone. Therefore commercial growth was 8.9 percent less than expected and public growth was 6.6 percent greater than expected (table 3). Since much of the rugged and relatively unpopulated land in the Northeast is either in public ownership or is owned by large timber companies, the fact that actual public campground market growth was greater than expected growth in such areas is not too surprising. Public campgrounds were already extensively developed in unsettled areas of the Northeast before 1961. Commercial campground development in mountainous regions was probably less than one would expect because of the lack of nearby population demand centers and the relative scarcity of private land ownership. Public campgrounds, not necessarily required to operate at a profitable level, can apparently locate in sparsely populated areas far from demand centers.

Forty-one percent of the land area in the Northeast is contained in the few-small-isolated empty-area zone. However, 46.3 percent of the commercial growth and only 32.7 percent of the public growth occurred in that zone. Commercial campground market growth was 5.2 percent greater than expected and public growth was 8.4 percent less than expected (table 3). This relationship illustrates the relative flexibility of the commercial sector of the camping market to locate near populated areas. Conversely, public campground development is less than expected in such areas, perhaps because public land is scarce and expensive near population centers.

The above market growth relationships reflect the complementary relationship between the commercial and public sectors

of the total camping market. Public campgrounds have located in relatively remote areas, without necessarily being associated with distance from population centers. In terms of empty-area zones, the combined effect of the growth in commercial and public sectors of the campground market has been to produce a higher level of total campground supply—in terms of overall services provided—than if either sector existed alone to satisfy total camping demand.

Forest Cover

A third factor of the physical environment that was studied for its association with camping market growth was forest cover. Forest cover was described for the Northeast by grouping counties into four forest-cover zones: 0 to 24 percent, 25 to 49 percent, 50 to 74 percent, and 75+ percent forested.

The percent of commercial and public campground growth occurring in the four forest-cover zones was approximately equal to the proportion of land area in each zone. However, public campground growth was slightly overrepresented in the more densely forested zones and somewhat underrepresented in the lightly forested zones. Commercial growth showed an opposite relationship: it was slightly underrepresented in the densely forested zones and somewhat overrepresented in the lightly forested zones. Although the observed differences between the actual and expected growth percents within forest-cover zones were not large, the observation does add some weight to earlier results indicating that public campground growth has been associated with wild land and heavily forested areas, while commercial campground growth has not been associated with wild land resource areas to the same extent.

Topography

Four general land-surface zones were used to associate campground market growth to surface terrain: Mountainous, hilly, flat, and coastal (fig. 5).

Actual commercial camping market growth occurring in the mountainous zone was approximately equal to expected growth

(table 4). Actual public campground market growth, however, exceeded expected growth in mountainous areas by 9 percent. In the hilly zones actual commercial growth was approximately equal to expected growth, but public campground market growth was 14 percent less than expected.

Both commercial and public campground growth were negatively associated with flat land surface, and positively associated with coastal zones. In flat areas, actual commercial growth was 5.4 percent less than expected, and public growth was 5.1 percent less than expected. Apparently, predominantly flat regions are

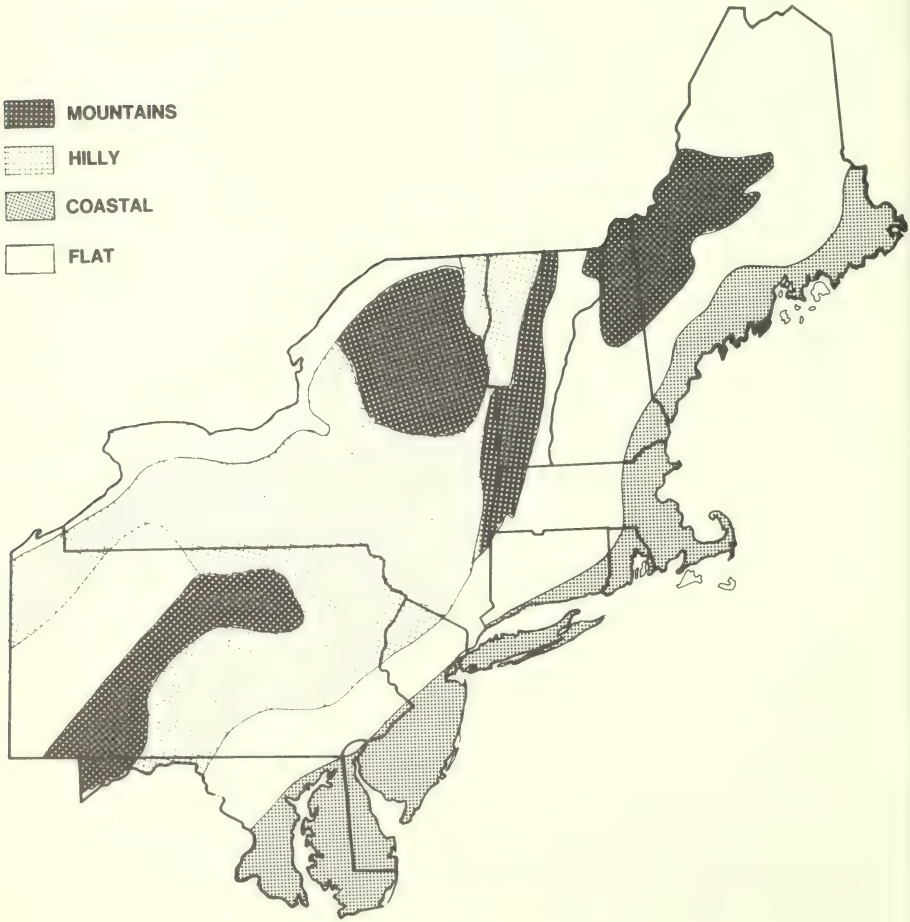


Figure 5.—General land-surface forms in the Northeast. Adapted from *A Forest Atlas of the Northeast*, by Howard W. Lull, USDA Forest Serv. NE. Forest Exp. Sta., 1968.

Table 4.—*Campground market growth in relation to land-surface form, 1961-67*

Land-surface form zone	Expected campground market growth[1]	Actual campground market growth			
		Type of campground	Year	Campgrounds in zone	Proportion of total growth within zone[2]
	Percent			*No.*	*Percent*
Mountains	19.9	Commercial	1961	22	17.2
			1967	239	
		Public	1961	104	28.9
			1967	134	
Hilly	25.5	Commercial	1961	11	27.3
			1967	358	
		Public	1961	46	11.5
			1967	58	
Flat	32.9	Commercial	1961	58	27.5
			1967	407	
		Public	1961	63	27.9
			1967	92	
Coastal	21.7	Commercial	1961	69	28.0
			1967	424	
		Public	1961	60	31.7
			1967	93	

[1]Expected campground market growth = percent of the total Northeastern study area contained in each land-surface form zone.

[2]Proportion of total growth = $\frac{\text{Commercial (or public) campground growth in the zone (1961-67)}}{\text{Total commercial (or public) campground growth in the Northeast (1961-67)}}$.

not desirable for extensive commercial or public campground development, unless some other attraction exists such as a major water resource or historical attraction. In the coastal area, actual commercial growth exceeded expected growth by 6.2 percent, and public growth was 10.1 percent greater than expected. This relationship supports an earlier finding that water resources are extremely important to the location of both commercial and public campgrounds.

The distribution of campground market growth relative to topography shows that land-surface form is more strongly associated with public campground market development than with commercial growth. Growth of commercial campgrounds was

roughly proportional to the land area contained in the four land-surface zones. Actual public growth, however, was disproportionate to the land area in all four zones; that is, in the mountainous and coastal zones, public growth was greater than expected, while in flat and hilly areas, public growth was less than expected.

MARKET GROWTH AND DEMAND

Two indicators were used to associate campground market growth and demand. The purpose of the first was to examine the association between camping market growth and distance from major population centers. The purpose of the second demand indicator was to determine the association between market growth and local population density.

Distance from Population Centers

A system of proximity-to-demand zones surrounding major population centers was used to investigate the association between campground market growth and distance from potential demand centers. Proximity-to-demand zones were determined by drawing circles with a 100-mile radius around all metropolitan areas in the Northeast having a population of at least ½ million. Resulting 100-mile-radius zones were grouped on the basis of size of the population they represented. Demand 'potentials represented by the zones were added wherever zones overlapped. Five proximity-to-demand zones were determined: A ½ to 1 million zone; a 1 to 5 million zone; a 5 to 10 million zone; a more than 10 million zone; and a zone made up of land area falling outside the 100-mile proximity zones.

Actual commercial and public campground growth was distributed in approximate proportion to the land area contained in each of the five proximity-to-demand zones. The actual growth and expected growth differed appreciably in only one zone—the area more than 100 miles from major urban centers. In this zone, both commercial and public growth was 8.1 percent less than the expected growth.

Local Population Density

The second indicator of demand related campground market growth to local population density. Counties were grouped into six population-density zones: 0 to 74, 75 to 149, 150 to 299, 300 to 599, 600 to 1,199, and 1,200 or more people per square mile.

Campground growth in the six population-density categories showed no association with local population density. The amount of campground growth occurring in each county population-density zone was approximately what would be expected if growth were distributed randomly over the entire Northeast.

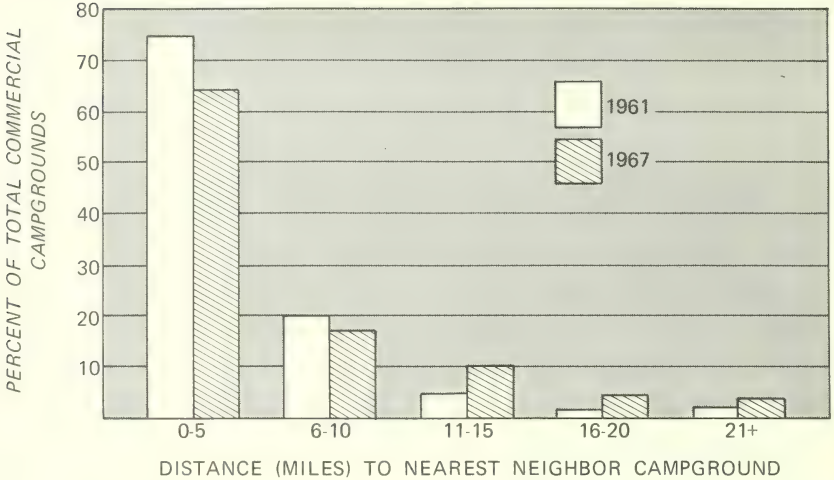
Although other more precise spatial demand indicators may have shown different results, the rather crude indicators of demand used above suggest that neither distance from demand centers nor local population density are associated with commercial or public camping market growth. However, further study, using more precise demand indices, is needed to provide more insight into the nature of the association.

MARKET GROWTH AND CLUSTERING

Camping market growth from 1961 to 1967 was associated with the distribution of campgrounds that existed at the beginning of the period. The relationship between the spatial distribution of campgrounds existing in 1961, and subsequent market growth to 1967, indicates a high degree of interdependence or complementarity within the camping market, as it developed over the 6-year growth period.

Even though the number of commercial campgrounds increased 8-fold during the 6-year period, the spatial distribution of campgrounds within the camping market remained fairly consistent (fig. 6). In 1961, almost 75 percent of commercial campgrounds were located within 5 miles of another commercial or public campground. By 1967, this proportion had decreased slightly to 65 percent. In 1961, 4.2 percent, and in 1967, 15.6 percent of commercial campgrounds were more than 10 miles from another campground.

Figure 6.—Commercial campground growth in relation to distance from nearest public or commercial campground, 1961 and 1967.

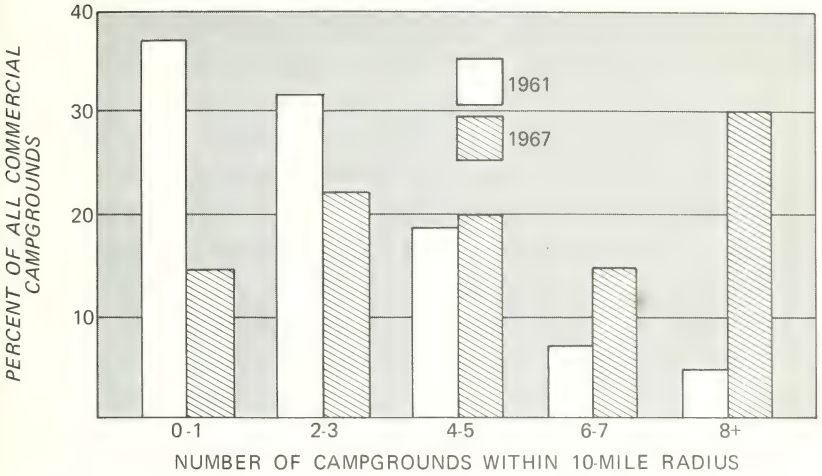


Another method used to describe locational relationships in the campground market was a campground clustering measure based on the number of campgrounds falling within a 10-mile radius of each existing campground.

In 1961, 70 percent of commercial campgrounds had less than 4 commercial or public campgrounds within a 10-mile zone, and 5 percent had at least 8 other campgrounds within a 10-mile radius. By 1967, the camping market had become much more clustered, 35 percent of commercial campgrounds having fewer than 4 commercial or public campgrounds within a 10-mile radius, and 29 percent of commercial campgrounds having at least 8 other campgrounds within a 10-mile radius (fig. 7).

Through the 1961-67 period, the Northeastern camping market became highly clustered, with new market growth occurring near existing campgrounds. Clustering of campgrounds can be attributed to at least two factors. First, as considered earlier, campgrounds tended to concentrate in areas containing resources with recreation attraction or appeal. Second, spatial clustering within the market may have resulted from complementary market relationships among campgrounds. Localization economies, re-

Figure 7.—Number of campgrounds within a 10-mile radius of existing commercial or public campgrounds, 1961 and 1967.



sulting in complementary services and facilities, may enhance campground clustering in the same way that other kinds of businesses tend to cluster together for mutual economic benefit. Clustering of campgrounds around a central area tends to give the particular area a regional identity, thereby providing the opportunity for joint regional advertising campaigns.

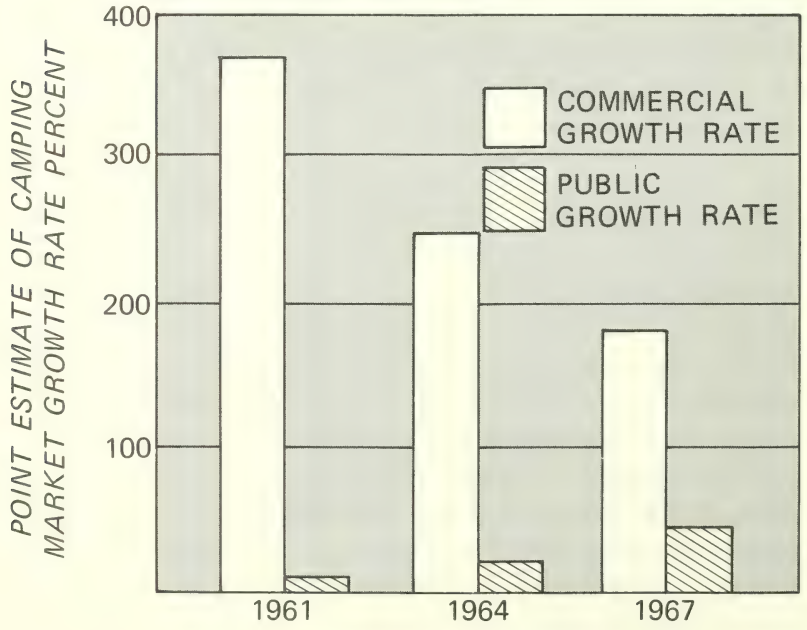
MARKET GROWTH TRENDS

Camping market data used in this study were compiled by cross-referencing campground directories for the three years 1961, 1964, and 1967. Because of the relative scarcity of camping directories and subsequent under-reporting, the inventory of campgrounds may be incomplete for 1961. By 1967, many campground directories were produced, and campgrounds may have been somewhat over-reported because of cross-indexing and reporting errors. Although these potential sources of error are recognized, little can be done about them, because no single source of campground inventory data was available for the entire 6-year study period.

Market growth trends were determined by measuring the rate of change in the growth of the commercial and public camping markets for the years 1961, 1964, and 1967. The growth-rate measurements describe the percent rate of growth in the camping market, at a particular point in time, and provide a basis on which to base future camping market growth predictions.

The growth rate of the commercial camping market was greater than the public market growth rate throughout the 6-year study period (fig. 8). In 1961, commercial campgrounds in the Northeast were increasing at the rate of 375 per cent per year, while the public growth was 9 percent per year. By 1967, the commercial camping market growth rate had decreased to 189 percent and the public growth rate had increased to 38 percent. Though the number of campgrounds in the commercial campground market has been increasing rapidly, the growth has been increasing at a decreasing rate, just as a man nearing a mountain

Figure 8.—Commercial and public camping market growth rate in the Northeast, 1961, 1964, 1967.



top climbs higher, but at a slower rate. On the other hand, the public campground market has been growing at an increasing rate.

The commercial camping market growth pattern is typical of any new market where demand exceeds effective supply. Initially, the commercial camping market developed rapidly because of growing demand for camping facilities. As the supply of commercial campgrounds started to meet the demand in some regions, the growth rate started to decline. In some areas, where market supply saturation occurred, the growth of commercial campgrounds may have stopped, while in other areas, where demand was still not met, growth continued at an increasing rate. In numbers of campgrounds, the commercial camping market is continuing to expand, but at a reduced rate, a trend that is likely to continue in the future (fig. 8).

While total growth occurring in the public camping market has been less than in the commercial market, the public camping market rate of growth has continued to increase slowly. The increase in the rate of public camping market growth is a reflection of public policy, at all levels of government, to meet the growing demand for public camping facilities. If current public policy is continued, the public camping market is likely to continue to grow at an increasing rate.

SUMMARY AND CONCLUSION

The 1961 to 1967 camping market growth in the Northeast was examined to relate market growth patterns to selected geographic features, population distribution, and existing campground locations.

Commercial and public camping market growth was positively associated with proximity to major water resources: approximately 60 percent of total camping market growth occurred within 5 miles of major water resources. However, opposite market growth relationships were found between the commercial and public camping markets when growth was associated with geographic resource distributions other than water. While public market growth was associated with unsettled, heavily forested, and moun-

tainous zones; commercial growth was less than expected in such zones. Conversely, commercial market growth was associated with relatively settled areas, and with less heavily forested zones. Commercial camping market growth was not, however, associated with topography.

Two population-related measures were used to indicate the association between camping market growth and potential demand for camping. The purpose of the first demand measure was to relate camping market growth to distance from large metropolitan centers, and the other to relate growth to local population density. Neither of these demand indicators was associated with camping market growth.

Campground clustering increased through the 6-year study period. Though campground clustering was related to the distribution of recreation resources, complementary relationships between clustered campgrounds and resulting regional localization economies also could be important in influencing market structure.

Total growth curves for the commercial and public camping markets were used to measure camping market growth rates for the years 1961, 1964, and 1967. Through this period, the rate of growth in the commercial market was always larger than the rate of growth in the public market. However the commercial camping market growth rate showed a downward trend, while the public growth rate trend increased gradually through the study period.

In numbers of campgrounds, the total camping market is likely to continue to grow in the future, but at a slower rate than in the past. The future camping market growth rate will, however, be influenced by the growth in camping demand, and by changes in public policy.

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EARLY CROP-TREE RELEASE

in even-aged stands of Appalachian hardwoods

by George R. Trimble, Jr.

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FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
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GUIDELINES NEEDED

NOW THAT EVEN-AGED silviculture is well established as a successful method of growing Appalachian hardwoods, a pressing need exists for guidelines for precommercial operations.

We started research several years ago on the Fernow Experimental Forest near Parsons, West Virginia, to learn more about the cost and methodology of early crop-tree release in mountain hardwood stands. In addition, we designed studies to evaluate the biological response of stands and stems to various treatments or combinations of treatments to get some measure of their response in the framework of a practical type of operation.

In our study, selected crop trees were released at an early age from the competition of surrounding woody stems. In addition, grapevines were cut out of the crop trees. The objective was to improve the species composition of the final stand, favor stems of superior quality, and shorten the rotation by giving the crop trees more space to grow. The success of this operation will eventually be determined by an evaluation of the biological response of the crop trees weighed against the cost of the operation.

In this paper, we are reporting on costs and methodology and discussing the factors to be considered in carrying out this operation; we have only 2-year measurement data on the biological response to our treatments. However, competition within these young stands is intense; and release of crop trees in such cases has generally proved beneficial (*Downs 1942; Conover and Ralston 1959; Williams 1964; Allen and Marquis 1970*).

PROCEDURES AND RESULTS

Our research gave us considerable information that should be useful to foresters who contemplate doing crop-tree release work. The fact that the study areas covered a total of 88 acres adds significance to the applicability of the results. A number of factors should be considered in planning this type of work, and the forester should ask himself these questions before proceeding:

- At what age—or at what stage of stand development—should a crop-tree release be made?
- How many crop trees per acre should be selected?
- What type of trees should be selected—species, crown class, stem form?
- Who is qualified to select crop trees?; how should these trees be designated?
- What method should we use to release crop trees?; how heavy should be the release?
- What can we expect this operation to cost?

Timing of the Crop-Tree Release

We felt that crop trees could not satisfactorily be selected until the new stand had closed and crown dominance was expressed. In the six areas where we did crop-tree releases, dominance was satisfactorily expressed when the stands were 7 to 9 years old; three of the stands met the criterion at 7 years, one at 8 years, and two at 9 years (table 1). We released the crop trees immediately after this condition was met because we felt that the sooner we did the job, the greater was our opportunity to improve species composition and maintain rapid growth. In a similar operation at Bartlett, New Hampshire (*Blum and Filip 1962*), it proved feasible to select crop trees in 10-year-old stands of even-aged hardwoods.

Site index (for oak) in our areas ranged from 63 feet to 77 feet (table 1); we found no relationship, within the range of our data, between the time the stands closed and site quality. Perhaps the influence of other factors obscured it.

Table 1. — Basic data on the crop-tree release areas

Area number	Area	Oak site index	Age at time of release	Release trees per acre	Selecting and designating crop trees		Releasing crop trees	
					Time per acre	Trees per man-hour	Time per acre	Trees per man-hour
	Acres	*Feet*	*Years*	*No.*	*Man-hours*	*No.*	*Man-hours*	*No.*
				5-FOOT RADIUS RELEASE				
43	12.2	77	7	109	2.3	47	6.0	18.1
38	13.2	63	7	117	1.8	64	10.3	11.4
36	12.1	68	9	84	4.4	19	10.4	8.1
Total	37.5	—	—	—	—	—	—	—
Weighted average	12.5	—	—	104	2.8	44	8.9	12.5
				JUDGMENT RELEASE				
39	16.9	71	7	111	(1)	(1)	3.6	30.1
34	11.2	63	8	109	(1)	(1)	3.0	35.9
32	22.0	76	9	124	(1)	(1)	3.8	32.9
Total	50.1	—	—	—	—	—	—	—
Weighted average	16.7	—	—	116	—	—	3.6	32.6
Total weighted average	14.6	—	—	111	—	—	5.9	24.0

[1] Releaser designated trees; all time was included under release work.

Our observations lead us to believe that a high proportion of sprout growth favors early stand closure (area 38, table 1), while extremely heavy herbaceous cover (area 32, table 1) and high density of grapevines (area 36, table 1) hold back tree growth and slow up canopy closure. In area 36, grapevines had to be cut out of 60 percent of the crop trees!

Number of Released Trees Per Acre

We released crop trees on a spacing of about 20 x 20 feet, or about 109 stems per acre. (We found that maintaining a 20 x 20 spacing was not difficult; measuring between trees was not necessary.) This is many more trees than are needed for the final sawtimber crop; and enough, if the majority survive, to make up a high portion of the last thinning.

The number of trees actually released in the six areas varied from 84 to 124 per acre and averaged 111 (table 1). The area in which we picked only 84 trees was so densely occupied by grapevines that, in parts of it, we were hard put to find suitable stems to release.

Type of Trees Selected for Crop Trees

In the site index 80 areas, we found enough black cherry and yellow-poplar stems to select a preponderance of these two species (table 2). On the site index 70 areas, we also found these two species but were forced to pick more stems of other species, too—such as red oak and sugar maple. In the two areas of lowest site—site index 60 for oak—we released red oak, chestnut oak, and red maple stems in that order. In all site classes, the selected crop-tree stand had a more desirable species mixture than the unselected stand of dominant stems (table 3).

We favored seedlings and seedling sprouts but were obliged to select some stump sprouts (table 2, fig. 1, fig. 2).

We tried to select vigorous trees of good form; that is, those with healthy-looking crowns and unforked straight stems.

Table 2. — Crop trees by origin for the four most numerous species

Area	10-foot site index class (for oak)	Release trees by species and origin[1]							
		1		2		3		4	
		Seed-ling	Sprout	Seed-ling	Sprout	Seed-ling	Sprout	Seed-ling	Sprout
43	80	*Yellow-poplar*		*Black cherry*		*White ash*		*Sugar maple*	
No. stems/acre		59	0	38	0	7	0	2	0
Percent of total no.		55	0	35	0	6	0	2	0
32	80	*Yellow-poplar*		*Black cherry*		*Basswood*		*Sugar maple*	
No. stems/acre		42	0	31	0	9	18	9	0
Percent of total No.		35	0	25	0	7	15	7	0
39	70	*Yellow-poplar*		*Black cherry*		*Basswood*		*White ash*	
No. stems/acre		45	2	31	7	5	7	4	2
Percent of total No.		40	2	28	6	4	6	4	2
36	70	*Sugar maple*		*Yellow-poplar*		*Red oak*		*Black cherry*	
No. stems/acre		20	5	11	7	13	2	13	0
Percent of total No.		25	6	13	8	16	2	16	0
38	60	*Red oak*		*Chestnut oak*		*Red maple*		*Yellow-poplar*	
No. stems/acre		41	20	16	20	2	16	2	0
Percent of total No.		35	17	14	17	2	13	2	0
34	60	*Red oak*		*Chestnut oak*		*Red maple*		*White oak*	
No. stems/acre		29	13	13	14	9	18	5	2
Percent of total No.		27	12	12	13	8	16	5	2

[1] Seedlings include seedling sprouts; stems from stumps 2 inches and less in diameter.

Table 3. — Comparison of the four most numerous species between the crop-tree population and the dominant reproduction population of the areas

Area and population	Four most numerous species in numerical order			
	1	2	3	4
43				
Crop trees	Yellow-poplar	Black cherry	White ash	Sugar maple
Dominant reproduction	Sugar maple	Black cherry	Yellow-poplar	White ash
32				
Crop trees	Yellow-poplar	Black cherry	Basswood	Sugar maple
Dominant reproduction	Sweet birch	Sugar maple	Black cherry	White ash
39				
Crop trees	Yellow-poplar	Black cherry	Basswood	White ash
Dominant reproduction	Sugar maple	Yellow-poplar	Sweet birch	Black cherry
36				
Crop trees	Sugar maple	Yellow-poplar	Red oak	Black cherry
Dominant reproduction	Sugar maple	Sassafras	Yellow-poplar	Red maple
38				
Crop trees	Red oak	Chestnut oak	Red maple	Yellow-poplar
Dominant reproduction	Sassafras	Black gum	Chestnut oak	Red maple
34				
Crop trees	Red oak	Chestnut oak	Red maple	White oak
Dominant reproduction	Sassafras	Chestnut oak	Sweet birch	Red maple

Figure 1. — A released black cherry seedling sprout.

Figure 2. — A yellow-poplar stump sprout flagged to be released.

Crop-Tree Selection and Stem Designation

Foresters, well-trained technicians, and competent woodsmen all selected crop trees in the study areas. Our experience convinced us that, *with clear direction and some training*, any conscientious experienced woodsman can do the job. It seemed to us that the role of a forester in this type of work should be to set the guidelines on the ground at the start of each operation.

We picked crop trees in five of the six treated areas when the leaves were off; in the other area, we selected and designated crop trees when the stand was in foliage. We could see better without the leaves, and the work went faster; we probably did a better job of selecting crop trees, too.

We designated crop trees by tying a piece of plastic flagging to a branch or stem. Where we did separate operations of selecting and releasing crop trees, the man picking the tree tied the flagging on; and the release crew pulled it off after the stem was released. Tying the flagging on as he progressed kept the designator oriented and enabled him to maintain good spacing; removing it enabled the release crew to know where they had worked and move across the areas in orderly fashion. No other physical guides were necessary.

When the same man both designated and released crop trees, he tied a piece of flagging to the tree after release and left it there. In this way, he kept himself oriented.

Method of Release

In the beginning, we debated whether to use chemical or physical methods of release. We decided against the chemical (with the size stems involved, this would logically have been a basal spray job) for the following reasons: (1) We would have difficulty getting around in the thick briary young stands with spraying equipment and with refill supplies. (2) We reasoned that it would take a great quantity of spray to treat the hundreds of small stems per acre that were in competition with the crop trees, and in such stands it would require time-consuming care not to damage the crop trees in treating their competitors —all adding up to a really costly operation. (3) We could not hand-spray one or several stems in a group of stump sprouts to release a companion sprout without killing it—and stump sprouts represented 23 percent of our selected trees. And (4) in the dense young stands it appeared that we would run a risk of root grafts between treated stem and crop tree.

So we decided to cut the stems, and after some preliminary testing with ax, machete, and the Woodsman's Pal, chose the Woodsman's Pal as the preferred tool (fig. 3). The Sandvik bush ax was found satisfactory in a similar study in New Hampshire (*Blum and Filip 1962*). Most of the stems cut were between ½ inch and 3 inches d.b.h. The Woodsman's Pal served equally well in cutting these and in severing grapevines. It was heavy enough to girdle the few larger stems.

Figure 3. — The Woodsman's Pal.

In eliminating competing stems, we cut them at the most convenient height, following the suggestion of Jemison and Hepting (*1949*). We also followed their advice in selecting and releasing single stems of sprout clumps; that is, we chose low-origin sprouts from U-shaped clumps.

In the three areas where the trees were designated ahead of the release job (43, 38, and 36), a separate crew did the release work. Each man carried a 5-foot measuring stick which he used in determining the 5-foot release radius around each crop tree. Within this radius, he cut all the woody stems that were over half as tall as the crop tree; he also cut the grapevines out of each crop tree.

In the three areas where the same man both designated and

released crop trees at one time (areas 39, 34, and 32), we used a different procedure—a "judgment" release: the releaser cut only those stems whose crowns were encroaching upon the crop-tree crown. This meant that he did practically no cutting around dominant stems, some around codominant stems, and a lot around intermediate stems—including reaching out beyond the 5-foot radius for offending competitors. Overall, this method called for much less cutting; and because of this and the fact that only one trip across the area was necessary, the whole release job went faster (table 1).

These areas—39, 34, and 32—were treated during the dormant season; and because we underestimated the degree of crowding, we probably did not release hard enough; the following summer the competing crowns appeared to be crowding the crop tree more than had seemed to be the case the previous winter.

Cost of the Operation

Where designation and release were carried out as two separate operations, 2.8 man-hours per acre were required, on the average, for selecting and designating crop trees; or a man did 44 trees per hour (table 1).

Actual release work required, on the average, 8.9 man-hours per acre; or a man released 12.5 trees per hour (table 1).

The complete job required 11.7 man-hours per acre on the ground (vehicle travel costs, planning time, and other overhead time were not included). At a rate of $2.00 an hour, the cost was $23.40, plus about $0.75 per acre for flagging.

In the second method, where the designator also released the crop trees, progress was much faster. The job required only 3.6 hours per acre, and the man selected and released 32.6 trees per hour (table 1). At $2.00 per hour, the cost was $7.20, plus the cost for flagging.

The difference in cost between the two types of operation is considerable—$23.40 compared to $7.20. The difference may be exaggerated, however, because area number 36 (one of the study areas in the first group) was the most difficult of all areas to work. In addition, crop-tree selection in this area was

made with the leaves on the trees. If area 36 is left out of the comparisons, the costs are $20.40 versus $7.20, which is still a big difference in favor of the second method.

RECOMMENDATIONS

First, we believe that, in most situations for which crop-tree releases are planned, the job should be postponed until the stand is 9 to 12 years old. A number of reasons support this recommendation: (1) By this age the stand will be easier to work in because the briary-thicket stage will have passed. (2) Crown dominance will be well expressed, so that potential crop trees will be easy to select. (3) Sprout regrowth of cut stems will be less likely to outgrow released trees. And (4) regrowth of severed grapevines will be less apt to remount into crop-tree crowns.

Potential disadvantages of waiting this long are: (1) There might be less opportunity to favorably influence species composition. And (2) if stump sprouts are selected for crop trees, cutting the companion sprouts will provide increased chance of rot entry with increasing diameter of cut stems.

Future research may uncover other disadvantages of waiting this long; but to date, indications favor waiting.

Second, we recommend the use of "judgment" release by carefully trained woodsmen. Release work should be done in the dormant season by mechanical, rather than chemical, means. Deliberate care should be taken to release hard enough since crowns without leaves appear less crowded than they actually are.

Third, we recommend that selection among intolerant species be restricted to dominant and codominant stems; but where appropriate, the better intermediate trees of tolerant species may be released. This is in accord with the work of Jemison and Hepting (*1949*). Moreover, 2-year measurements on some of our release areas indicate that release of subdominant intolerant species may be largely a waste of time because they appear to retrogress quickly in dominance.

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■

APPENDIX

List of common and scientific names of species referred to in this study.

Ash, white	*Fraxinus americana* L.
Basswood	*Tilia americana* L.
Beech	*Fagus grandifolia* Ehrh.
Birch, sweet	*Betula lenta* L.
Cherry, black	*Prunus serotina* Ehrh.
Grape	*Vitis*
Gum, black	*Nyssa sylvatica* Marsh.
Maple, red	*Acer rubrum* L.
Maple, sugar	*Acer saccharum* Marsh.
Oak, red	*Quercus rubra* L.
Oak, chestnut	*Quercus prinus* L.
Sassafras	*Sassafras albidum* (Nutt.) Nees.
Yellow-poplar	*Liriodendron tulipifera* L.

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An Appraisal of

OAK WILT CONTROL PROGRAMS

in Pennsylvania and West Virginia

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An Appraisal of OAK WILT CONTROL PROGRAMS in Pennsylvania and West Virginia

A THREAT TO OAK FORESTS

OAK WILT, caused by the fungus *Ceratocystis fagacearum* (Bretz) Hunt, is a threat to oak forests in the 21 States where it is known to occur. Catastrophic losses to this disease, feared by many in its early history, have fortunately not materialized. Still, thousands of oaks succumb to oak wilt annually, and there is no assurance that this rate of loss is static.

Attempts to control oak wilt, ranging from relatively small-scale experiments to statewide programs, have been made in many States. Among the few currently active, those of Pennsylvania and West Virginia are notable for their size and duration. The pest-control organizations of the Pennsylvania Department of Agriculture and the West Virginia Department of Agriculture have vigorously pursued well-organized statewide oak wilt control programs in their respective States for more than 15 years. Further, these organizations, in cooperation with the Northeastern Area Branch of State and Private Forestry and the Northeastern Forest Experiment Station of the USDA Forest Service, have, since 1958, conducted special studies to measure the effectiveness of these control efforts. This is a report on the results of those studies through 1968.

THE CONTROL PROGRAMS

The oak wilt fungus spreads from diseased trees to healthy trees in at least two ways: below ground through naturally occurring root grafts, and above ground by insect vectors. Control measures employed in both Pennsylvania and West Virginia are designed to prevent spread by reducing or isolating the fungal inoculum at its source.

The Pennsylvania Method

In the Pennsylvania control program, an aerial detection survey is made, providing complete coverage of the infected portion of the State. More heavily infected areas are resurveyed as many as five times each year. Ground surveys are also made incidental to checking all suspect trees located from the air. Diseased oaks and healthy oaks within 50 feet of and of the same species group as the diseased tree are felled. Stumps of all diseased and healthy trees cut are poisoned with the herbicide Ammate.

The diseased trees are felled to hasten drying and reduce the number of fungus mats formed between the bark and wood. These mats are a source of inoculum for spread of the fungus by sap-feeding beetles. The surrounding healthy trees are cut to prevent spread by root grafts and to prevent aboveground spread of the pathogen by eliminating the nearest suscepts. Herbicide application to the stumps hastens root kill, shortening the time that the roots can serve as reservoirs of inoculum and pathways of below-ground fungus spread.

The West Virginia Method

In the West Virginia control program an aerial detection survey is made, providing complete coverage of the entire State. The more heavily infected areas are resurveyed as frequently as every 2 weeks during the growing season. Supplementary ground surveys are made incidental to checking all

suspect trees located from the air. All diseased trees located are treated by chopping a girdle into the heartwood, completely around the tree at a convenient height. The bark on the bole and buttress roots from the girdle to ground line is removed. The deep girdle and basal bark removal hastens drying of the tree, thus preventing or reducing the formation of fungus mats.

CONTROL PROGRAM APPRAISAL STUDIES

The first study to appraise oak wilt control programs was made from 1958 through 1963. The results: 77 percent fewer diseased trees occurred on plots treated by the Pennsylvania method and 46 percent fewer diseased trees on plots treated by the West Virginia method than on check plots receiving no treatment (*Jones 1965*). Of equal importance was evidence that rate of fungus spread on check plots increased with time.

However, unavoidable features in the design of this study caused reservations about the validity of results. Chief among these was the segregation of treatments. The Pennsylvania method was applied only to plots in Pennsylvania, the West Virginia method only to plots in West Virginia; and the majority of the check plots were located in western Maryland between the other two States.

A second study has now been made, with several revisions in design, to refine the estimates of control-program effectiveness and the rate of fungus spread in untreated areas. The appraisal was made on 2.9-acre circular plots, each centered on an oak wilt infection center. An oak wilt infection center is a wilt-infected or wilt-killed tree, or a group of such trees, any one of which is not more than 50 feet from another wilt tree. A wilting tree more than 50 feet from other wilt trees is in a separate infection center.

These plots were selected to meet certain specifications so that a degree of uniformity between study areas was assured. The appraisal plot specifications were:

- The plot to be circular, 400 feet in diameter, and centered on an oak wilt infection center.
- The infection center to consist of not more than five wilting or wilt-killed trees, at least one of which is of the red oak group, 6 inches d.b.h. or larger, wilting at the time the plot is established.
- At least five healthy oaks of the red oak group, 2 inches d.b.h. or larger, to be within 50 feet of the diseased oaks, with similar oak stocking on the remainder of the plot.
- Each plot center to be at least 300 feet away from any other known wilt center or dead wilt suspect.
- Partial plots to be acceptable if their inclusion is essential to obtaining the specified number of plots. Partial plots are those in which a field, powerline clearing, road, stream, or nonoak timber type infringe on the plot. Such infringement to be at least 50 feet from the plot center.

Table 1.—Number of control appraisal plots by location and treatment

Plot location	Control method		
	Pennsylvania method	West Virginia method	No control
	No.	*No.*	*No.*
A. NEW PLOTS, ESTABLISHED 1964–66			
Pennsylvania	26	24	24
West Virginia	36	36	35
Subtotal	62	60	59
B. OLD PLOTS, ESTABLISHED 1958–61			
Pennsylvania	41		3
West Virginia		52	24
Maryland			5
Subtotal	41	52	32
Total	103	112	91

Seventy-four plots were established in Pennsylvania and 107 plots in West Virginia in 1964–66 (table 1A). One of three treatments—the Pennsylvania method, the West Virginia method, or no treatment—was assigned in rotation to each plot when it was established. Trees wilting when the plot was established were treated by the method assigned to the plot. Each plot was carefully examined twice each summer through 1968, and the wilting trees found by these examinations were treated by the assigned method. Thus each of the three control treatments was applied to approximately one-third of the plots in each State. Oak wilt spread was recorded from the time of plot establishment through 1968—from 2 to 4 years.

In addition, 125 plots from the old appraisal study met the new standards in 1964, and were maintained through 1968 as an adjunct to the main study (table 1B). Control treatment applied on these plots remained the same as originally assigned. The schedule for examination and treatment and the data recorded were the same for these old plots as for the new plots. Oak wilt spread on these plots was recorded for 7 to 10 years.

RESULTS AND DISCUSSION

The effects of control treatments were appraised by comparing incidence of oak wilt infection on control and check plots. Oak wilt incidence was determined as the number of infected trees and also as the number of active infection centers per plot per year. (An "active infection center" was one with a currently wilting tree.) The data were grouped and compared by years of plot age, measured from the time of establishment. Since plots were established over a period of several years, they become the same age in different calendar years, so this grouping of data tended to average the "normal" year-to-year fluctuation of wilt incidence. Disease incidence on treated and check plots was also compared for the entire period of the study. Some plots were destroyed by fire or cutting

before the study was completed. The data for such plots were included, however, for so long as they met specifications. There were approximately the same number of partial plots among the control and check plots. Results determined with and without partial plots were essentially identical, so data from partial plots were included without special identification.

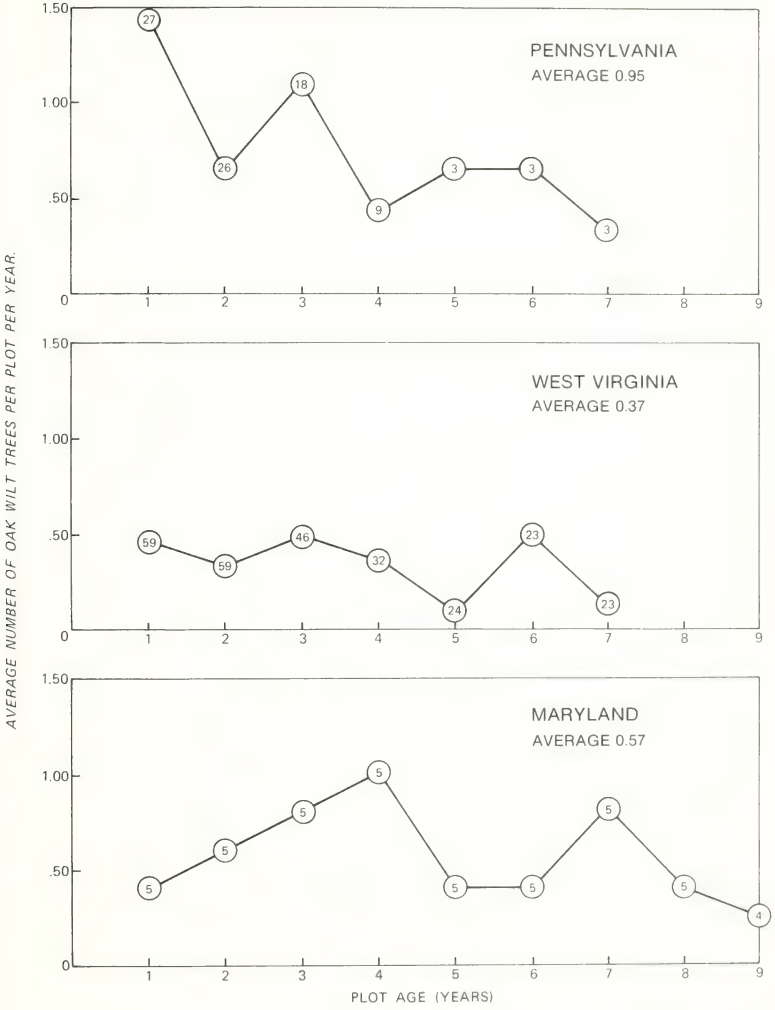
Check Plots

The annual levels of oak wilt infection on check plots were determined from the combined data from both the old and new study (fig. 1). At least two significant conclusions may be drawn. First, the tendency for rate of oak wilt spread to increase with time, as suggested by results of the first study alone, was not substantiated by these combined data. No clear-cut trend was apparent, but there were indications that infection centers tend to become less active rather than more active as time passes. Second, frequency of fungus transmission, at least within 200 feet of existing infection centers, was greatest in Pennsylvania (0.95 trees per plot per year), somewhat lower in Maryland (0.57 trees per plot per year), and still lower in West Virginia (0.37 trees per plot per year).

The relation between incidence of infection and distance from previously diseased trees on check plots in this study (fig. 2), confirmed the spread pattern reported for the first appraisal study and those for West Virginia and North Carolina discussed by True *et al.* (*1960*). Most wilt infections within our plots occurred very close to the apparent source of inoculum. Of the 295 trees that became infected on check plots subsequent to their establishment, 13 percent were within 10 feet of a previously diseased tree, 47 percent within 20 feet, 66 percent within 30 feet, 81 percent within 40 feet, and 88 percent within 50 feet. The remaining 12 percent or 37 trees were scattered, apparently at random, 50 to 200 feet from previously diseased trees.

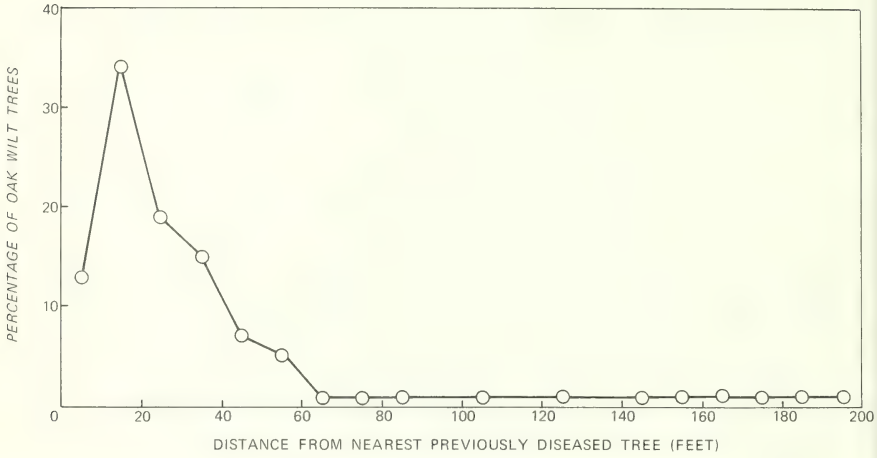
Although oak wilt spread that could be measured on these plots was heavily concentrated within 50 feet of previously diseased trees, spread over greater distances does readily

Figure 1.—Number of oak wilt trees per plot per year by plot age on check plots in Pennsylvania, Maryland, and West Virginia. The encircled numbers indicate number of plots on which average was based.



occur. In 1969, for example, 23 percent of the active infection centers in Pennsylvania and 50 percent of the active infection centers in West Virginia were new centers resulting from spread of the fungus for more—often very much more—than 50 feet from previously diseased trees (*Jeffery and Tressler 1969; anonymous 1969*).

Figure 2.—Frequency distribution of oak wilt trees by distance from nearest previously diseased tree on check plots in Pennsylvania, Maryland, and West Virginia.



It is evident that this study should provide a satisfactory measure of the effect of the control treatments on local spread of the fungus. ("Local spread" is spread of the fungus to trees within 50 feet of previously diseased trees.) It was initially believed that comparing wilt incidence on check and control plots from 50 out to 200 feet from plot infection centers would also provide a measure of the effect of control treatments on long-distance spread of the fungus. ("Long-distance spread" is spread of the fungus to trees more than 50 feet from a previously diseased tree.) However, very few wilt infections occurred in this area on the check plots—an average of only 0.06 trees per plot per year in Pennsylvania, and 0.09 trees per plot per year in West Virginia. So the sampled areas were too small for adequate appraisal of control of this kind of spread.

The Pennsylvania Control Method

With the Pennsylvania control method, fungus spread was reduced on plots in Pennsylvania, northeastern West Virginia, and southern West Virginia by 90 percent, 100 percent, and

97 percent, respectively (table 2). Only 9 trees became infected on the 62 plots receiving this treatment as opposed to 98 new wilt trees on the 59 check plots. The degrees of control by this method, based on the number of active infection centers rather than the number of wilting trees, were 84 percent, 100 percent, and 93 percent, respectively.

In the Pennsylvania method, all healthy oaks within the local spread zone and of the same species group as the diseased tree are cut. Therefore, local spread of the fungus can occur only between trees of different species groups or to trees of the same species group left standing due to oversight in applying

Table 2.—PENNSYLVANIA CONTROL METHOD: Number of wilt trees per plot by plot age for plots established 1964-66

Plot age (years since establishment)	Control			No control		
	Plots	Wilt trees	Wilt trees per plot	Plots	Wilt trees	Wilt trees per plot
PENNSYLVANIA						
1	26	4	0.15	24	32	1.33
2	26	2	.08	23	14	.61
3	17	1	.06	15	18	1.20
4	10	1	.10	6	2	.33
Average per year	19.7	2.0	0.10	17.0	16.5	0.97
Control = 90 percent						
NORTHEASTERN WEST VIRGINIA						
1	17	0	0	16	4	0.25
2	17	0	0	16	5	.31
3	11	0	0	9	4	.44
4	5	0	0	4	1	.25
Average per year	12.5	0	0	11.2	3.5	0.31
Control = 100 percent						
SOUTHERN WEST VIRGINIA						
1	19	1	0.02	19	3	0.16
2	19	0	0	19	5	.26
3	14	0	0	13	9	.69
4	11	0	0	4	1	.25
Average per year	15.7	0.2	0.01	13.7	4.5	0.33
Control = 97 percent						

Table 3.—PENNSYLVANIA CONTROL METHOD: Number of wilt trees per plot by plot age for plots established 1958-61 in Pennsylvania

Plot age (years since establishment)	Control			No control		
	Plots	Wilt trees	Wilt trees per plot	Plots	Wilt trees	Wilt trees per plot
1	41	7	0.17	3	7	2.33
2	41	6	.15	3	3	1.00
3	41	4	.10	3	2	.67
4	40	5	.12	3	2	.67
5	40	3	.07	3	2	.67
6	39	3	.08	3	2	.67
7	39	4	.10	3	1	.33
Average per year	40.1	4.6	0.11	3.0	2.7	0.90
	Control = 88 percent					
8	30	0	0	—	—	—
9	19	0	0	—	—	—
10	7	0	0	—	—	—
Average per year	33.7	3.2	0.09	—	—	—

the control treatment. Of the nine new wilt trees on plots so treated, two resulted from long-distance spread, one from apparent local spread from a red oak to a chestnut oak, and the other six from apparent local spread from infected red oaks to red oaks that were missed in application of the control measures.

The results obtained over a period of 10 years with the Pennsylvania control method on the old appraisal plots are shown in table 3. Only three check plots met specifications for 7 years of this period, so a good comparison between control and no control is not possible. Nonetheless, the indicated degree of control—88 percent—and the annual incidence of wilt on control and check plots agree very closely with corresponding values from the more recent study and so contribute to our confidence in the reliability of the results reported.

The West Virginia Control Method

With the West Virginia control method, fungus spread was reduced in Pennsylvania, northeastern West Virginia, and southern West Virginia by 39 percent, 0 percent, and 79 percent, respectively (table 4). Comparable values based on number of active infection centers rather than number of wilting trees were 26 percent, 3 percent, and 83 percent.

Table 4.—WEST VIRGINIA CONTROL METHOD. Number of wilt trees per plot by plot age for plots established 1964-66

Plot age (years since establishment)	Control			No control		
	Plots	Wilt trees	Wilt trees per plot	Plots	Wilt trees	Wilt trees per plot
PENNSYLVANIA						
1	24	18	0.75	24	32	1.33
2	24	19	.79	23	14	.61
3	15	5	.33	15	18	1.20
4	8	0	0	6	2	.33
Average per year	17.7	10.5	0.59	17.0	16.5	0.97
Control = 39 percent						
NORTHEASTERN WEST VIRGINIA						
1	17	10	0.59	16	4	0.25
2	17	7	.41	16	5	.31
3	11	5	.45	9	4	.44
4	5	1	.20	4	1	.25
Average per year	12.5	5.7	0.46	11.2	3.5	0.31
Control = none						
SOUTHERN WEST VIRGINIA						
1	19	0	0.00	19	3	0.16
2	18	2	.11	19	7	.26
3	13	1	.08	13	7	.69
4	5	1	.20	4	1	.25
Average per year	13.7	0.5	0.07	13.7	4.5	0.33
Control = 79 percent						

There is no clear reason for the variation in results with this method in the three test areas. Oak wilt infection centers are far more numerous in northeastern West Virginia than in the southern part of that State or in Pennsylvania. On the other hand, the rate of fungus spread immediately around known infection centers on check plots was nearly identical for the

Table 5.—WEST VIRGINIA CONTROL METHOD: Number of wilt trees per plot by plot age for plots established 1958-61

Plot age (years since establishment)	Control			No control		
	Plots	Wilt trees	Wilt trees per plot	Plots	Wilt trees	Wilt trees per plot
NORTHEASTERN WEST VIRGINIA						
1	21	21	1.00	24	20	0.83
2	21	8	.38	24	10	.42
3	21	6	.29	24	9	.37
4	21	13	.62	24	10	.42
5	21	6	.29	24	2	.08
6	21	10	.48	24	11	.48
7	21	14	.67	23	3	.13
Average per year	21.0	11.1	0.53	24.0	9.3	0.39
	Control = none					
8	21	10	.48	—	—	—
9	17	6	.29	—	—	—
10	4	0	0	—	—	—
Average per year	18.9	9.4	0.50	—	—	—
SOUTHERN WEST VIRGINIA						
1	31	9	0.29	—	—	—
2	31	6	.19	—	—	—
3	31	5	.16	—	—	—
4	31	6	.19	—	—	—
5	31	7	.23	—	—	—
6	31	8	.26	—	—	—
7	31	9	.29	—	—	—
8	31	6	.19	—	—	—
9	19	1	.05	—	—	—
10	7	1	.05	—	—	—
Average per year	27.4	5.8	0.21	—	—	—

two areas in West Virginia but was much higher in Pennsylvania. The unknown factors responsible for these significant but seemingly inconsistent differences may well be involved in the variable responses to the West Virginia control method.

The results obtained over a period of 10 years with the West Virginia control method on the old appraisal plots are shown in table 5. Sufficient data are available to compare oak wilt incidence on control and check plots in northeastern West Virginia for 7 of those 10 years. These data confirm the conclusion drawn from the more recent study that this control method is ineffective against local spread in the northeastern part of the State. A similar comparison cannot be made for southern West Virginia because none of the check plots in the old study was located there. It can be noted that in this area the number of wilt trees per plot per year on treated plots in the recent study has been held to 0.07 (table 4) as compared with a corresponding value of 0.21 for treated plots in the old study.

CONCLUSIONS

The Pennsylvania control method prevented nearly all spread of the oak wilt fungus to trees in the immediate vicinity of treated infection centers. It was about equally effective in all test areas from Pennsylvania to southern West Virginia. Instances of spread after treatment were rare, and two-thirds of these could be accounted for by incomplete application of the control measures. However, these excellent results were accomplished at a high—and perhaps unacceptable—cost in healthy trees destroyed. About seven healthy trees were cut for each infected tree treated; and this may be more than would be lost to local spread of the pathogen if no control were attempted.

The West Virginia control method was less effective in suppressing local oak wilt spread than the Pennsylvania method in all areas. However, it is much cheaper to apply and does not destroy healthy trees. In southern West Virginia this method provided a high degree of control, and considering its lower

costs for labor and impact on healthy trees, it would appear to be the better method for that part of the State. The performance of this control measure in Pennsylvania was marginal at best, and there was no evidence that it reduced local spread of the fungus in northeastern West Virginia.

The results of this study have provided reliable and well-documented information about the local spread potential of the oak wilt pathogen in Pennsylvania and West Virginia. We can now predict, with a high degree of confidence, what future losses will be in the immediate vicinity of existing and new infection centers if they are not controlled. We know how much these losses can be reduced by applying either of the two control practices.

But these studies failed to measure the amount and importance of long-distance spread of the wilt fungus that results in new infection centers. Nor have we learned how effective either control measure is in reducing this type of spread. These were important objectives of the study that were not attained because of major differences between anticipated and actual study results.

The annual numbers of active infection centers in all of Pennsylvania for the period 1964–68 were 281, 271, 294, 279, and 261. Analogous figures for West Virginia were 3,011, 2,472, 2,047, 2,228, and 2,406. Yearly variations in these figures reflect the effect of weather, other natural phenomenon, financing, and the number and experience of available personnel on survey efficiency as well as real differences in oak wilt incidence; so the oak wilt situation in both States for this 5-year period can be characterized as relatively stable. We know that disease losses in both States would be greater were it not for the control programs, but we have only a partial basis for estimating how much greater.

A new study to provide this information was started in 1969 and is scheduled for completion in 1973. It is specifically designed to measure uncontrolled long-distance spread of the wilt fungus and the effectiveness of the Pennsylvania and West Virginia control programs in suppressing such spread. Infection center multiplication is a vital factor in the disease complex,

so a complete and valid appraisal of the oak wilt threat in these States and realistic biologic and economic evaluation of the control programs must await the outcome of that study.

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and Robert L. Brisbin

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SAWLOG GRADES for EASTERN WHITE PINE

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SAWLOG GRADES for EASTERN WHITE PINE

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FOREWORD

IN 1957, the USDA Forest Service Log Grade Committee recommended a service-wide action program in log- and tree-grade research. Approval of the program in 1958 resulted in the establishment of five species-oriented timber-quality research projects covering several groups of commercially important timber species.

The eastern softwood timber-quality project was activated in 1960. Its initial objective was to develop improved log and tree grades for eastern white pine. This paper presents the results of this initial research.

The project staff thank the many individuals and organizations who contributed time and services to this research effort, including Regions 8 and 9 of the National Forest System; the Minnesota Agency, Bureau of Indian Affairs; the New York State University College of Forestry at Syracuse, N. Y.; the Maine Forest Service; the Northeastern Lumber Manufacturer's Association and the Northern Hardwood and Pine Manufacturer's Association and their member sawmill operators.

INTRODUCTION

ALTHOUGH EASTERN WHITE PINE now accounts for only a small percentage of the total national softwood lumber production, it does hold a prominent position in the timber economies of New England, portions of the Lake States, and the Southern Appalachian area. Because of the extreme variability in quality of white pine timber, a grading system that will accurately and consistently stratify sawlogs into distinct value classes is necessary for timber appraisal and management purposes.

After the New England hurricane of 1938, the USDA Forest Service developed an arbitrary set of eastern white pine log-grade specifications for use in its timber-salvage program. These specifications proved reasonably adequate for this program, but questions arose about identification and evaluation of certain grading factors in the system. The lack of consideration for other important quality criteria also suggested need for improvement. In addition, performance tables for the system were limited to the rough green lumber condition without consideration of log diameter, thus reducing the accuracy of the system.

Sporadic use of these rules by the Forest Service and other Government agencies continued through the mid-1940's, and these rules were also adopted for use in the Forest Survey. Within this same period, a number of companies and associations also developed grading systems for the species. All of these fell short of satisfying basic objectives and desirable performance standards.

DEVELOPMENT OF THE IMPROVED SYSTEM

In 1955 the Northeastern Forest Experiment Station, in cooperation with the State University of New York College of Forestry at Syracuse, N. Y. began a study to develop an improved sawlog-grading system for eastern white pine. The study resulted in an improved grading system that was designated as the "trial" sawlog-grade specifications for eastern white pine.

Additional white pine lumber-grade yield studies were conducted in Maine and New Hampshire in 1957, 1958, and 1960 (fig. 1). Analysis of data from these studies indicated that the "trial" system was superior to the old "timber-salvage" grading system and also suggested several minor modifications. Data for all Northeastern studies were then combined and the improved "trial" grade specifications, with accompanying lumber-grade yield tables, were made available for use in the Northeast.

In 1960, timber-quality research in eastern softwoods was given project status as part of the overall Forest Service log- and tree-grade program. Testing of the "trial" white pine log-grading system over the species' range was begun. Tests were made in the Lake States and the Southern Appalachians (fig. 1). Results of these tests also indicated that the "trial" system satisfactorily met the standards desired of a good log-grading system. In 1969 the Forest Service Log Grade Committee recommended that the system be accepted as the Forest Service standard, and this was approved in 1970.

GRADING PROCEDURE

GENERAL CONSIDERATIONS

The specifications for the approved system (fig. 2) apply to *cut* eastern white pine sawlogs. They are not recommended for use in grading logs in standing trees—separate specifications have been developed for grading standing trees. Also, they do not apply to logs from artificially pruned trees. The grades are

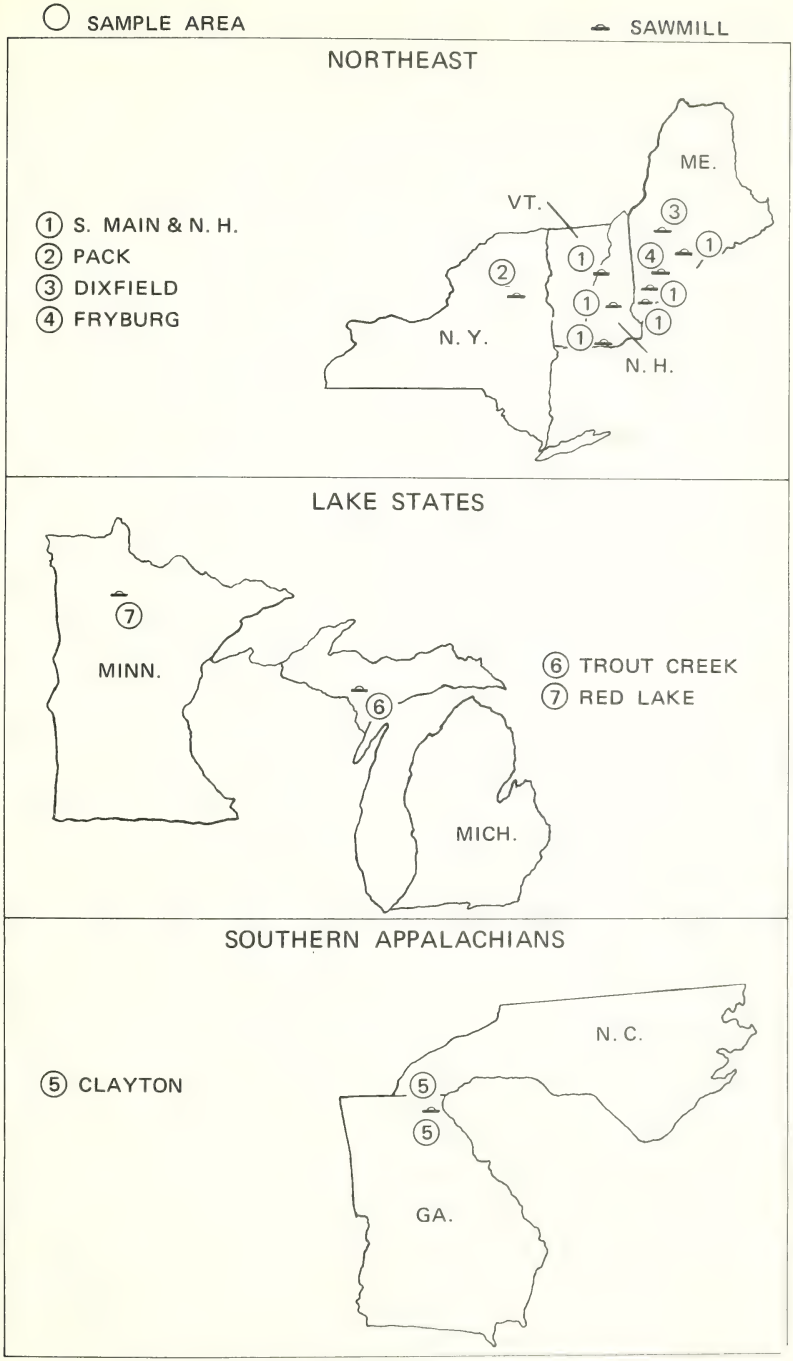

Figure 1.—Location of sample areas and study sawmills.

EASTERN WHITE PINE SAWLOG GRADE SPECIFICATIONS

GRADING FACTOR	LOG GRADE 1	LOG GRADE 2	LOG GRADE 3	LOG GRADE 4
(1) MINIMUM SCALING DIAMETER (inches)	14[1]	6	6	6
(2) MINIMUM LOG LENGTH (feet)	10[2]	8	8	8
(3) MAXIMUM WEEVIL INJURY (number)	None	None	2 injuries[3]	No limit
(4) MINIMUM FACE REQUIREMENTS	Two full length or four 50% length good faces.[4] (In addition, log knots on balance of faces shall not exceed size limitations of grade 2 logs.)	No GOOD FACES REQUIRED. Maximum diameter of log knots on three best faces: SOUND RED KNOTS not to exceed 1/6 scaling diameter and 3 inch maximum. DEAD OR BLACK KNOTS including overgrown knots not to exceed 1/12 scaling diameter and 1½ inch maximum.	SOUND RED KNOTS not to exceed 1/3 scaling diameter and 5 inch maximum. DEAD OR BLACK KNOTS including overgrown knots not to exceed 1/6 scaling diameter and 2½ inch maximum.	Includes all logs not qualifying for No. 3 or better and judged to have at least one-third of their gross volume in sound wood suitable for manufacture into standard lumber.
(5) MAXIMUM SWEEP OR CROOK ALLOWANCE (percent)	20	30	40	66⅔
(6) MAXIMUM TOTAL SCALING DEDUCTION (percent)	50	50	50	66⅔

After the tentative log grade is established from face examination, the log will be reduced in grade whenever the following defects are evident:

(7) CONKS, PUNK KNOTS, AND PINE BORER DAMAGE ON BARK SURFACE[5]

Degrade one grade if present on one face.
Degrade two grades if present on two faces.
Degrade three grades if present on three or more faces.

(8) LOG END DEFECTS: RED ROT, RING SHAKE, HEAVY STAIN AND PINE BORER DAMAGE OUTSIDE HEART CENTER OF LOG[5]

Consider log as having a total of 8 quarters (4 on each end) and degrade as indicated below:
Degrade one grade if present in 2 quarters of log ends.
Degrade two grades if present in 3 or 4 quarters of log ends.
Degrade three grades if present in 5 or more quarters of log ends.

[1]12 and 13 inch logs with four full length good faces are acceptable.
[2]8 foot logs with four full length good faces are acceptable.
[3]8 foot No. 3 logs limited to one weevil injury.
[4]Minimum 50% length good face must be at least 6 feet.
[5]Factors 7 and 8 are not cumulative (total degrade based on more serious of the two). No log to be degraded below grade 4 if net scale is at least one-third gross log scale.

Figure 2.—Grading specifications for eastern white pine sawlogs.

based on the external surface characteristics of the species—more specifically, on the extent of "good" faces and the size and condition of log knots in relation to log diameter. Evidence of white-pine weevil injury, sweep, crook, red ring rot, ring shake, and pine borer damage may also act as degrading factors.

The log grades are designed for stratifying logs into distinct value classes and predicting differences in the lumber-grade yield of logs sawed into standard yard lumber, as defined by the Northeastern Lumber Manufacturer's Association and the Northern Hardwood and Pine Manufacturer's Association.

GRADING FACTORS AND DEFINITION OF TERMS

The following description of grading factors and definitions of terms used in grading are presented in the same order as in the specifications (fig. 2).

(1) *Log diameter.*—A log must have at least a 6-inch scaling diameter to be graded. Grade 1 logs have further limits on scaling diameter.

(2) *Log length.*—Logs 8 to 16 feet long can be graded with these rules. There are further limits on length for grade 1 logs.

(3) *Weevil injury.*—Evidence of weevil injury can be recognized by moderate to severe crook at the point of injury. Crook is usually more serious in small logs than in large logs. Limbs at point of injury are usually large and acute-angled. Logs showing none of these characteristics are considered free of weevil injury.

(4) *Minimum face requirements.*—A log face is defined as one-fourth the circumference of the log surface for the full length of the log. A *good* face is one that is free of log knots of any type larger than ½ inch in diameter, overgrowths indicating larger knots, and conks or punk knots. A half face is one-half the length of the log. *Good* half faces can be in either half of a full face and must be at least 6 feet long for 10-foot logs.

Log knots.—Sound red log knots are any visible branches, stubs, or sockets that resulted from living branches or branches that have been dead for a short time. They are intergrown with the surrounding wood and contain no rot. Dead or black log knots are visible branches, stubs, or sockets that do not conform to the definition of sound red knots. Overgrown log knots are identified by a distinctive circular or elliptical pattern in the bark, and they are treated the same as dead knots. Size of the branch stub underlying the overgrowth can be estimated by observing the adjacent visible log knots. The average diameter of live or dead knots is measured at the point where the limb would

normally be trimmed from the log. If the knot resulted from a live branch, only the diameter of the red heartwood portion is considered in determining knot size; if the knot resulted from a dead branch or stub, the total limb diameter is considered. All knots ½ inch or less in diameter are disregarded.

(5) ***Maximum sweep or crook allowance.***—Sweep is the deviation in inches of the curved central log axis from a straight line connecting the centers of each end of the log. The percent volume loss due to sweep is:

$$\text{Percent sweep} = \frac{\text{Sweep minus one for each 8 feet of log length}}{\text{Log diameter (inches)}} \times 100$$

Crook is an abrupt curve or bend deviating from the straight longitudinal axis of the log. The percent volume loss due to crook is:

$$\text{Percent crook} = \frac{\text{Deviation (inches)}}{\text{Log diameter (inches)}} \times \frac{\text{Log length affected (feet)}}{\text{Total log length (feet)}} \times 100$$

(6) ***Maximum total scaling deduction.***—Total deductions include sweep and crook deductions as well as volume deductions for other scalable defects (rot, shake, insect damage, etc.).

(7) ***Conks, punk knots, and borer damage on bark surface.***—A conk is the fruiting body of a wood-rotting fungus (generally *Fomes pini* in eastern white pine). A punk knot is completely rotten, and the brown mycelial mass of the rot fungus is visible within the knot. Pine borer damage is evidenced by entrance channels (holes 3/16 to ½ inch in diameter) on the bark surface.

(8) ***Log-end defects.***—Red ring rot (incipient and advanced stages of decay due to *Fomes pini*) is usually associated with overmature or badly weeviled trees. It can be recognized on log ends by its reddish brown to pink color. It should not be confused with the brown cubical rot usually found in the butts of older trees. Ring shake is a separation of wood fibers along an annual ring; it is usually associated with older trees. Heavy blue

stain is a blue fungal discoloration limited to the sapwood. The color is so pronounced that it nearly obscures the grain of the wood. It usually accompanies an insect attack in logs stored during periods of warm weather. Pine borer damage on log ends is evident from occurrence of entrance channels (holes 3/16 to ½ inch in diameter) on log ends.

APPLICATION

The following procedure is recommended for grading white pine sawlogs:

1. First, scale the log, following standard Forest Service scaling practice *(USDA Forest Service 1964)*. Proper scaling procedures automatically give the grader measurements of many of the factors involved in grading the log. These include log diameter and length, severity of sweep or crook, and evidence of red rot, ring shake, or borer damage.
2. Then examine the log for possible weevil injuries.
3. Assign a tentative grade to the log, based on log size limitations, allowable scale deduction, weevil injury, and face requirements (factors 1 through 6 in specifications).
4. After the tentative grade is established, determine whether degrade is necessary due to factors 7 and 8.

PERFORMANCE OF THE GRADING SYSTEM

The tabulated dressed-dry lumber-grade recoveries for each geographic area and log grade were calculated from quadratic regression equations of percent lumber-grade yield over log diameter (tables 1 through 12). Separate lumber-grade recoveries are required for each geographic area because of differences in lumber-grading rules between two areas and because of the high incidence of weevil injury in the Northeastern area. The curved lumber-grade yields are an average estimate for each geographic area. Therefore it is not likely that they will precisely predict the output of any particular mill. Because sawing patterns and lumber thicknesses may vary from mill to mill, users of

these grades should develop performance data that are tailored specifically to their own particular sets of conditions; i.e., sawing patterns and lumber size mix.

The recovery tables for the Northeastern area reflect the yields of 1,549 logs from 22 different timber stands in New York, New Hampshire, and Maine. The sample logs were sawed into 4/4 standard yard lumber at nine sawmills within this area. The recovery tables for the Southern Appalachian area are based on 498 logs sawed at one circular mill. Both 4/4 and 8/4 standard yard lumber was produced. In both the Northeastern and Southern Appalachian areas the lumber was graded according to the rules of the Northeastern Lumber Manufacturer's Association. In the Lake States area, 753 logs from 6 medium- to old-growth stands were converted into 4/4 and 8/4 standard yard lumber at 2 band mills. The lumber was graded according to the rules of the Northern Hardwood and Pine Manufacturer's Association.

The distribution of the sample logs by scaling diameter and log grade within each area (table 13) is an indication of the relative precision of the lumber-grade recovery tables. A reasonably good distribution exists in most log grades except for the larger diameters (greater than 20 inches). However, the occurrence of logs larger than 20 inches in diameter is limited throughout most of the range of the species.

The lumber grade yields differ among the three sample areas, particularly in log grades 2, 3, and 4. The higher percentage of No. 3 Common lumber in log grades 3 and 4 of the Southern sample can be attributed to less weevil injury and better natural pruning characteristics. The higher percentage of No. 2 and No. 3 Common lumber in the Lake States sample, as compared to the Northeastern sample, resulted from differences in the lumber-grading systems used. The percentage of No. 5 Common lumber in the grade 4 logs of the Lake States sample is higher because of the greater incidence of red rot.

In the Northeastern and Lake States areas a substantial price differential by board width exists within several of the lumber grades. Because of this, the distribution of lumber widths in each lumber grade and log-diameter class is important. We found

that a substantial difference in lumber-width class distribution existed between the select and common grades of lumber (table 14). Log grade did not have a significant effect on width-class distribution after scaling diameter and lumber grade were considered. The distribution percentages can be applied to the curved yields to provide an estimate of the lumber-grade yields by width class.

To effectively use the lumber-grade yield tables for estimating lumber recovery, log overrun data must be developed for converting log-scale volume to lumber-tally volume. Overruns depend on several factors such as the log rule used to estimate the volume, the type of sawmill used to convert the logs into lumber, and the size and mix of products produced from the logs.

We have computed the overruns for each of the three sample areas for the International 1/4-inch and Scribner Decimal C log rules (table 15). In the Northeastern area the computed overruns represent an average of nine circular sawmills. The overruns shown for the Southern and Lake States samples are based on only one and two mills respectively. Because of the numerous factors affecting overrun, users of the system should develop their own overrun values.

DISCUSSION

The standard Forest Service grades for eastern white pine logs presented in this report resulted from many years of research, with cooperative effort from the lumber industry. The system is recommended for use by log buyers, sellers, and processors throughout the commercial range of eastern white pine.

By using the log grades and accompanying lumber-grade yield tables, log buyers and sellers can estimate the value of logs in terms of standard yard lumber grades. Sawmill operators will find the log grades useful for estimating the proportions of the various lumber grades that can be produced from their graded log inventories. The grading specifications are also useful for determining proper bucking practice to provide the optimum yield of standard yard lumber.

The lumber-grade yield tables in this report represent the performance of better-than-average sawmills in the respective geographic areas. These tables will probably not predict precisely any particular mill's output because of differences in lumber thicknesses and sawing patterns. If a user of this grading system wants precise estimates of lumber-grade yields by log grade for his operation, he should conduct a mill-scale study at his own mill. He will also be able to develop overrun factors from the same study.

The application of this grading system will be simplified if it is used in conjunction with USDA Forest Service Research Paper NE-190 *(Ostrander 1971)*, which illustrates and explains the grading factors.

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APPENDIX A

PERFORMANCE TABLES

Table 1-12. — Curved lumber-grade yields, by log diameter for each log grade and sample area.

Table 13. — Distribution of logs in each sample area, by log grade and scaling diameter.

Table 14. — Lumber-width class distribution, by lumber grade and log diameter.

Table 15. — Percent overruns of the International ¼-inch and Scribner Decimal C rules for each sample area.

GRADE 1 LOGS — NORTHEASTERN AREA

Table 1.—*White pine curved lumber-grade yields by log diameter*

[Dressed-dry, basis: 86 logs]

Scaling diameter (inches)	D-Select & Better	No. 1 & 2 Common	No. 3 Common	No. 4 Common	No. 5 Common
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
12	38	24	25	13	(*)
13	38	21	25	15	1
14	39	18	25	17	1
15	39	15	26	19	1
16	40	12	26	20	2
17	41	11	25	21	2
18	42	10	25	21	2
19	43	9	24	22	2
20	44	9	23	22	2
21	46	9	21	22	2
22	48	10	19	22	1
23	50	11	17	21	1

*Less than 0.5 percent.

GRADE 2 LOGS — NORTHEASTERN AREA

Table 2.—*White pine curved lumber-grade yields by log diameter*
[Dressed-dry, basis: 194 logs]

Scaling diameter (inches)	D-Select & Better	No. 1 & 2 Common	No. 3 Common	No. 4 Common	No. 5 Common
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
6	4	39	44	13	(*)
7	6	35	44	15	(*)
8	8	31	43	18	(*)
9	10	27	43	20	(*)
10	11	23	42	23	1
11	12	20	42	25	1
12	13	17	41	28	1
13	14	14	40	30	2
14	15	12	39	32	2
15	16	10	37	35	2
16	16	8	36	37	3
17	17	7	34	39	3
18	17	6	33	41	3
19	17	6	31	43	3
20	16	6	29	45	4
21	16	6	27	47	4
22	16	6	24	49	5
23	16	6	22	51	5

*Less than 0.5 percent.

GRADE 3 LOGS — NORTHEASTERN AREA

Table 3.—*White pine curved lumber-grade yields by log diameter*
[Dressed-dry, basis: 844 logs]

Scaling diameter (inches)	D-Select & Better	No. 1 & 2 Common	No. 3 Common	No. 4 Common	No. 5 Common
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
6	1	12	50	36	1
7	1	10	48	40	1
8	2	8	46	43	1
9	2	7	44	46	1
10	2	6	42	48	2
11	2	5	40	51	2
12	3	4	38	53	2
13	3	3	36	55	3
14	4	3	34	56	3
15	4	3	32	58	3
16	4	2	31	59	4
17	5	2	29	60	4
18	5	2	27	61	5
19	6	2	25	61	6
20	7	2	23	61	7
21	7	2	22	61	8
22	8	3	20	60	9
23	8	3	19	60	10

GRADE 4 LOGS — NORTHEASTERN AREA

Table 4.—*White pine curved lumber-grade yields by log diameter*
[Dressed-dry, basis: 425 logs]

Scaling diameter (inches)	D-Select & Better	No. 1 & 2 Common	No. 3 Common	No. 4 Common	No. 5 Common
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
6	1	2	24	70	3
7	1	2	23	70	4
8	1	1	22	70	6
9	1	1	21	70	7
10	1	1	20	70	8
11	1	1	19	70	9
12	1	1	18	69	11
13	1	1	17	69	12
14	1	1	17	68	13
15	2	(*)	16	67	15
16	2	(*)	15	66	17
17	2	(*)	14	66	18
18	3	(*)	13	64	20
19	3	(*)	13	63	21
20	4	(*)	12	61	23
21	5	(*)	11	60	24
22	6	(*)	10	58	26
23	6	(*)	10	56	28

*Less than 0.5 percent.

GRADE 1 LOGS — SOUTHERN AREA

Table 5.—*White pine curved lumber-grade yields by log diameter*
[Dressed-dry, basis: 37 logs]

Scaling diameter (inches)	D-Select & Better	No. 1 & 2 Common	No. 3 Common	No. 4 Common	No. 5 Common
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
12	35	16	25	24	(*)
13	35	15	25	25	(*)
14	35	14	25	25	1
15	35	13	25	26	1
16	36	12	24	26	2
17	36	11	24	26	3
18	38	10	23	25	4
19	39	9	21	25	6
20	41	8	19	24	8
21	43	7	17	23	10
22	46	6	15	22	11
23	49	5	12	20	14

*Less than 0.5 percent.

GRADE 2 LOGS — SOUTHERN AREA

Table 6.—*White pine curved lumber-grade yields by log diameter*

[Dressed-dry, basis: 60 logs]

Scaling diameter (inches)	D-Select & Better	No. 1 & 2 Common	No. 3 Common	No. 4 Common	No. 5 Common
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
6	5	55	34	6	(*)
7	5	51	35	9	(*)
8	5	47	35	13	(*)
9	5	41	36	18	(*)
10	5	36	37	21	1
11	6	30	37	25	2
12	7	26	36	28	3
13	7	22	36	31	4
14	9	18	35	34	4
15	10	15	34	36	5
16	11	12	32	39	6
17	13	10	30	41	6
18	15	8	28	42	7
19	17	6	26	44	7
20	19	5	23	45	8
21	22	5	20	45	8
22	25	4	17	45	9
23	27	5	13	46	9

*Less than 0.5 percent.

GRADE 3 LOGS — SOUTHERN AREA

Table 7.—*White pine curved lumber-grade yields by log diameter*
[Dressed-dry, basis: 326 logs]

Scaling diameter (inches)	D-Select & Better	No. 1 & 2 Common	No. 3 Common	No. 4 Common	No. 5 Common
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
6	(*)	20	63	15	2
7	(*)	18	62	19	1
8	(*)	16	60	23	1
9	1	14	58	26	1
10	1	12	56	30	1
11	1	10	54	34	1
12	1	9	52	37	1
13	2	7	50	39	2
14	2	6	47	43	2
15	3	5	44	45	3
16	3	4	41	48	4
17	3	4	39	50	4
18	4	3	35	53	5
19	4	3	32	55	6
20	4	2	29	57	8
21	5	2	25	59	9
22	5	2	22	60	11
23	6	2	18	62	12

*Less than 0.5 percent.

GRADE 4 LOGS — SOUTHERN AREA

Table 8.—*White pine curved lumber-grade yields by log diameter*
[Dressed-dry, basis: 75 logs]

Scaling diameter (inches)	D-Select & Better	No. 1 & 2 Common	No. 3 Common	No. 4 Common	No. 5 Common
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
6	(*)	9	54	30	7
7	(*)	8	49	35	8
8	(*)	6	45	39	10
9	(*)	5	40	43	12
10	(*)	4	36	47	13
11	1	3	32	50	14
12	1	2	28	53	16
13	1	2	25	55	17
14	2	1	22	57	18
15	2	1	19	58	20
16	3	(*)	17	59	21
17	3	(*)	15	60	22
18	4	1	13	59	23
19	4	1	12	58	25
20	5	1	11	57	26
21	6	2	11	55	26
22	6	3	11	53	27
23	7	4	11	50	28

*Less than 0.5 percent.

GRADE 1 LOGS — LAKE STATES AREA

Table 9.—*White pine curved lumber-grade yields by log diameter*
[Dressed-dry, basis: 33 logs]

Scaling diameter (inches)	D-Select & Better	No. 1 & 2 Common	No. 3 Common	No. 4 Common	No. 5 Common
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
12	22	35	17	25	1
13	26	35	17	21	1
14	29	36	17	17	1
15	32	35	18	14	1
16	35	34	18	12	1
17	37	33	18	11	1
18	39	31	18	11	1
19	40	29	18	12	1
20	41	25	18	15	1
21	41	21	17	19	2
22	41	17	17	23	2
23	40	12	16	29	3

GRADE 2 LOGS — LAKE STATES AREA

Table 10.—*White pine curved lumber-grade yields by log diameter*
[Dressed-dry, basis: 168 logs]

Scaling diameter (inches)	D-Select & Better	No. 1 & 2 Common	No. 3 Common	No. 4 Common	No. 5 Common
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
6	(*)	67	30	3	(*)
7	(*)	66	29	5	(*)
8	1	62	29	8	(*)
9	3	56	29	10	2
10	5	51	28	13	3
11	7	47	28	14	4
12	8	42	28	17	5
13	10	38	28	18	6
14	12	34	28	20	6
15	13	31	29	21	6
16	15	28	29	22	6
17	16	25	30	23	6
18	17	22	31	24	6
19	18	19	32	25	6
20	19	17	33	26	5
21	20	15	35	26	4
22	20	14	37	26	3
23	21	12	39	27	1

*Less than 0.5 percent.

Table 11.—*White pine curved lumber-grade yields by log diameter*
[Dressed-dry, basis: 421 logs]

Scaling diameter (inches)	D-Select & Better	No. 1 & 2 Common	No. 3 Common	No. 4 Common	No. 5 Common
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
6	(*)	54	28	17	1
7	(*)	50	30	18	2
8	1	45	32	20	2
9	1	40	34	22	3
10	1	36	36	24	3
11	2	32	37	26	3
12	2	28	38	28	4
13	2	25	39	30	4
14	3	22	39	32	4
15	3	19	39	34	5
16	4	17	39	35	5
17	4	15	39	37	5
18	5	13	38	39	5
19	5	11	37	42	5
20	5	10	36	44	5
21	6	9	34	46	5
22	6	8	33	48	5
23	7	7	31	50	5

*Less than 0.5 percent.

Table 12.—*White pine curved lumber-grade yields by log diameter*
[Dressed-dry, basis: 131 logs]

Scaling diameter (inches)	D-Select & Better	No. 1 & 2 Common	No. 3 Common	No. 4 Common	No. 5 Common
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
6	1	17	31	34	17
7	1	16	28	35	20
8	1	14	26	36	23
9	1	13	23	38	25
10	2	11	21	38	28
11	2	10	19	39	30
12	3	9	17	40	31
13	3	8	16	41	32
14	3	8	15	41	33
15	4	7	14	41	34
16	4	6	14	42	34
17	5	6	14	42	33
18	5	6	14	42	33
19	6	6	15	41	32
20	7	6	16	41	30
21	8	6	17	41	28
22	9	6	19	40	26
23	9	7	21	39	24

Table 13.—*Distribution of logs in each sample area by log grade and scaling diameter*

[Number of logs]

Scaling diameter (inches)	Northeast: log grade—				Southern: log grade—				Lake States: log grade—			
	1	2	3	4	1	2	3	4	1	2	3	4
6	—	1	101	42	—	—	—	—	—	1	10	—
7	—	6	92	43	—	1	7	2	—	2	22	
8	—	18	100	64	—	—	32	5	—	5	56	
9	—	23	74	49	—	2	24	3	—	6	52	1
10	—	24	89	43	—	6	30	3	—	14	44	1
11	—	24	79	24	—	5	32	2	—	24	38	1
12	4	20	83	30	—	3	36	5	3	13	39	
13	13	14	61	22	2	4	23	1	1	19	30	
14	13	19	49	26	4	3	29	1	3	21	30	
15	11	8	28	22	4	2	20	2	6	17	19	1
16	9	13	30	19	2	3	24	3	3	11	22	1
17	12	10	19	12	2	5	17	5	3	8	13	
18	9	3	18	11	2	1	13	9	3	6	16	
19	6	7	6	7	2	6	9	5	3	—	11	
20	4	2	10	2	2	5	10	5	3	7	6	
21	2	1	2	2	5	3	7	4	—	3	2	
22	1	—	1	2	3	3	4	5	3	5	6	
23[1]	2	1	2	5	9	8	9	15	2	6	5	1
Total	86	194	844	425	37	60	326	75	33	168	421	13

[1]The 23-inch diameter class includes a few logs from 24 inches to 30 inches in several o the grades.

Table 14.—*Lumber width-class distribution by lumber grade and log scaling diameter*[1]

[In percent]

Scaling diameter (inches)	D-Select & Better: width class—			No. 1-5 Common: width class—		
	1	2	3	1	2	3
6	94	6	0	91	9	0
7	85	15	0	56	44	0
8	75	25	0	36	64	0
9	65	35	0	25	75	0
10	56	44	0	18	82	0
11	48	48	4	14	82	4
12	40	50	10	11	74	15
13	33	50	17	8	64	28
14	26	52	22	6	48	46
15	20	52	28	5	37	58
16	16	51	33	4	30	66
17	13	50	37	3	26	71
18	11	48	41	2	23	75
19	10	45	45	2	21	77
20	10	42	48	2	20	78
21	10	40	50	2	21	77
22	10	38	52	2	22	76
23	11	36	53	2	23	75

[1]Width class 1—(3 to 5 inches); width class 2—(6 to 9 inches); width class 3—(10 inches and wider).

Table 15.—*Percent overruns of the International ¼-inch and Scribner Decimal C rules for each sample area, by log diameter and soundness class*[1]

Scaling diameter (inches)	Northeast		Southern				Lake States			
	International		International		Scribner		International		Scribner	
	Sound	All[2]	Sound	All[2]	Sound	All[2]	Sound	All[2]	Sound	All[2]
6	7	8	—	—	—	—	22	24	48	51
7	7	6	22	24	58	59	19	20	53	54
8	7	6	18	19	47	48	17	19	45	46
9	5	4	10	9	33	33	16	16	44	42
10	3	3	5	5	25	25	12	13	36	38
11	1	1	5	4	24	23	11	13	34	36
12	—1	0	1	1	18	18	10	12	31	33
13	—2	—1	—2	—2	15	15	10	12	29	32
14	—2	—2	—6	—4	9	11	8	10	24	29
15	—2	—1	—5	—4	9	10	6	10	22	26
16	—2	—1	—6	—4	6	9	7	9	20	23
17	—1	—1	—4	—4	6	6	8	9	20	21
18	—1	—1	—6	—5	3	4	9	9	20	20
19	—2	—1	—5	—5	1	1	7	9	13	16
20	—2	—1	—8	—6	—3	—1	6	9	11	15
21	—2	—2	—7	—4	—3	0	4	5	9	11
22	2	—2	—8	—4	—4	1	5	5	11	11
23	6	—4	—7	—3	—2	2	5	5	12	11

[1]The values in this table were computed by summing the net log scales and lumber tallies of all logs within a diameter class and then calculating a rolling 3-group overrun for each scaling diameter.

[2]Includes both sound and unsound logs. Unsound logs are logs with scalable defect according to standard Forest Service scaling practices.

APPENDIX B

DEVELOPMENT AND TESTING OF THE GRADING SYSTEM

Several standards recommended by the Forest Service Log Grade Committee were followed in developing and testing this grading system *(Newport et al. 1958)*. These standards include:

1. The grades in a grading system must group the logs or trees so that variability in value or product yields is reduced to a reasonable limit.
2. For a given log size, one grade should differ from another by not less than 10 percent of the mean value of the higher of the two grades under consideration. The differences in mean value among the several grades should be approximately equal.
3. There should be no more than six grades within any grading system.
4. A grading system should be applicable to a particular species over its entire commercial range.

The initial study for developing white pine log grades consisted of a sample of 381 logs from northeastern New York. All surface characteristics of each log were recorded on diagram sheets before the logs were processed into lumber *(Ostrander et al. 1964)*. The logs were sawed into 4/4 standard yard lumber, and all lumber was graded and tallied in the rough-green, rough-dry, and dressed-dry conditions.

Two existing log-grading systems were available for application and testing on eastern white pine logs. These were the Northeastern Timber Salvage Administration (NETSA) white pine log grades and the interim southern pine log grades *(USDA Forest Service 1953)*. All sample logs were graded from the diagrams by these two grading systems. From the rough-green lumber-grade-recovery data and current lumber prices, a quality-index value was assigned to each log. The mean quality-index values for each log grade and the within-grade and pooled variances for the two grading systems were then computed. Results indicated that neither of the two grading systems adequately segregated the logs into distinct and uniform value classes. The within-grade variability of most grades was over three times as high as that recommended by the National Log Grade Commission report.

After a detailed analysis of the log diagrams, we isolated several important quality characteristics not recognized by the two grading systems. By combining these additional characteristics with the good points of the systems, we developed the "trial" eastern white pine log-grading system. The "trial" system resulted in a significant decrease in within-grade and pooled variances as well as more uniform differences in mean quality-index values among log grades.

Subsequently, several more samples of logs were obtained in Maine and New Hampshire. All logs were graded according to the two original systems and the new "trial" system. In each case the "trial" system resulted in a 30- to 35-percent reduction in pooled variance as compared to the NETSA and southern pine systems. After all studies in the Northeast had been analyzed separately, the data were combined and the "trial" log-grade specifications, with accompanying rough-green lumber-grade yield tables for the Northeastern area, were made available.

Since the "trial" system was developed from only Northeastern area data, additional samples of logs were needed to test the system in other areas within the commercial range of eastern white pine. Samples were obtained from both the Southern Appalachian and Lake States areas. All logs were diagrammed and graded by the NETSA and "trial" log-grading systems. The resulting lumber was graded in the dressed-dry condition by the chief inspectors from the respective lumber manufacturers' associations.

The statistical tests of the two grading systems (NETSA and "trial") in each sample area were made, using a general logarithmic regression model described by Newport and O'Regan *(1963)*. Total log value and dressed-dry lumber tally volume of each log were used as the dependent and independent variables respectively in the regression model. Separate sets of regressions were calculated for each sample area.

The analysis showed that the "trial" grading system as compared to the NETSA system reduced the pooled within-grade variance of actual log value by 41 percent in the Northeastern area, 14 percent in the Southern Appalachian area, and 30 percent in the Lake States area. In the Northeastern sample the within-grade variability of the NETSA system ranged from 14 to 19 percent. Within the "trial" system it ranged from 10 to 13 percent. The within-grade variability in the Southern sample ranged from 8 to 24 percent for the NETSA system and 9 to 15 percent for the "trial" system. In the Lake States sample it ranged from 14 to 36 percent for the NETSA system and 12 to 23 percent for the "trial" system. The difference in value between adjacent log grades of the "trial" system at a given log size was at least 10 percent, and it was relatively uniform in all cases. The value differences between log grades of the NETSA system were generally more erratic.

Even though the "trial" system resulted in lower pooled and within-grade variances in all three sample areas, we suspected that certain modifications of the system would result in further reductions, especially in the Lake States sample. In the first modification we reduced the maximum allowable dead knot size in log grades 2 and 3. However, this modification caused no appreciable reduction in pooled or within-grade variance. Further investigation of the lumber-grading rules showed that the Lake States rules permit a greater number of dead knots in the medium to high common grades of lumber than the Northeastern rules. Therefore, even though the dead knots appeared more serious in the Lake States sample logs, they did not affect the log values or lumber-grade yields.

In the second modification, we added two additional grades to the "trial" system. During the processing of the Lake States sample, we observed that several grade 3 and 4 logs were degraded only because of red ring rot in the log ends. We suspected that this type of log would have a different value and yield than the grade 3 or 4 log degraded because of knot size and condition. Therefore, in this modification grade 3 and 4 logs that were degraded only because of red ring rot were placed in two additional grades — grade 5 and grade 6 respectively. This modification caused slightly lower pooled and within-grade variances, although the differences were not significant. The addition of two grades to the system probably accounted for the slight reduction in variance.

Because the two modifications did not reduce variability to any significant degree, we felt that further improvement of the "trial" system was not possible without making the specifications unduly complicated.

THE FOREST SERVICE of the U. S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

The LANDOWNER & The SNOWMOBILER

—*Problem or Profit?*

by George H. Moeller

U.S.D.A. FOREST SERVICE RESEARCH PAPER NE-206
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NORTHEASTERN FOREST EXPERIMENT STATION, UPPER DARBY, PA.
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HARD & COLD

A CONFLICT is growing between landowners and snowmobilers. Many landowners think snowmobiles are a nuisance: noisy; trespassing on private land. Yet some landowners are cashing in on the new and fast-growing sport of snowmobiling by operating snowmobile enterprises. (*Moeller 1969*).

However, there are a few hard and cold facts that the landowner needs to consider before he invests his money in the snowmobile craze. The information presented here is based on case studies of eight commercial snowmobile enterprises in central New York State: on three golf courses, three farms, and two winter-sports areas.

MARKET POTENTIAL

Even though the snowmobile has proved to be of great practical value as a work vehicle, only 1 out of every 20 snowmobiles is used for work. The rest are used for recreation. Since 1962, snowmobile sales have grown at the rate of almost 50 percent each year (*Howe 1969*). Today over one million snowmobiles are operated in Canada and the United States.

The purchase of new snowmobiles has started to decline in some rural areas, and market analysts are now looking toward the urban resident for future sales (*Briggs 1969*). The problem of where to use snowmobiles in or near urban areas is serious. Restrictive zoning, posting of open areas within or near cities, and the time required to get to public snowmobile trails form barriers to participation for the urban snowmobiler. The scarcity of open land may have a significant influence on the future of snowmobiling.

With a growing interest in snowmobiling, and a movement

toward restricting land areas available for snowmobile use, the owner of open land, particularly near urban areas, may be in a position to profitably meet this new type of recreation demand (*Dunn 1970*). However, many things influence the success of a commercial snowmobile enterprise. What role can commercial enterprise play in meeting the growing demand for snowmobile services and facilities?

TYPES OF ENTERPRISES

Three types of commercial snowmobile enterprises were studied: golf courses, farm enterprises, and winter-sports areas.

Golf courses naturally attract snowmobile activity because they are usually located in or near urban areas where open space for snowmobiling is extremely limited. Golf-course facilities can be adapted easily to the needs of snowmobilers. Golf-course employees, who are usually idle during the winter, can be used to repair snowmobiles, maintain snowmobile trails, and enforce rules and regulations. Experienced small-engine mechanics employed during the summer are a particular asset to the golf-course snowmobile enterprise.

Two of the three central New York golf courses studied rented snowmobiles for $8 per hour. The third did not rent machines, but allowed snowmobilers to use their own snowmobiles on the course for a fee of $3.50 per day. A fee of $45, which included machine storage, was charged for a season's use.

The three farm snowmobile enterprises studied were located within a 1-hour drive of Syracuse, New York. Snowmobile enterprises provided farm operators with a supplemental source of income during their idle winter months. Farm operators controlled use of machines by allowing them to be driven only on designated trails. Farm snowmobile enterprise operators found that existing buildings could be adapted to provide basic facilities. They charged a snowmobile rental fee of $5 per hour or $20 per day. People owning their own machines were charged $2 per day.

The two winter-sports areas studied offered an array of indoor and outdoor activities to attract groups ranging from swinging singles to families. Winter activities included snowmobiling, ice-skating, tobogganing, and group sports. Indoor social activities included dances and group parties. However, the main attraction was snowmobiling. Although rental fees varied somewhat with snowmobile size, $8 per hour was the normal rental fee at both winter-sports areas. Rental of safety helmets, goggles, and snowmobile suits provided additional revenue.

Winter-sports area facilities were also utilized for recreation during the warmer months. One area had been operated as a campground, the other as a social recreation club with facilities for camping, swimming, fishing, and golfing. The advent of the snowmobile—and the resulting winter demand for commercial facilities and services—allowed the operators of these otherwise seasonal commercial recreation enterprises to extend their businesses on an annual basis. Appreciable savings resulted because facilities and labor were utilized more completely throughout the year. Many of the same people who took part in the summer recreation programs also participated in winter programs; however, operators of both areas said that participants in the winter programs tended to be a younger clientele, usually families with small children.

MANAGEMENT PROBLEMS

Several management problems were common to all three types of commercial snowmobile enterprises.

The most frequent problem was that rental machines were difficult to maintain. The enterprise operators felt that excessive machine breakdown was probably due to inexperienced snowmobilers who tended to drive machines too fast over smooth and relatively flat surfaces. One suggested solution to this problem was to restrict rental of machines to licensed automobile drivers, or to people over 16 years of age. An alternative suggestion was to have operators of rental

snowmobiles show financial responsibility by posting a $20 deposit.

Managers also felt that snowmobile maintenance problems could be reduced by preparing machines for rental. They suggested that rental machines should: (1) not exceed 18 hp; (2) have a track wide enough for stability; (3) be suited for family use; (4) have inexpensive bumpers; (5) be constructed so that the carburetor or motor cannot be tampered with; (6) have grip-bars installed on the rear; (7) have a safety device to disconnect the ignition if the operator falls off; and (8) be equipped with electric starters (fig. 1).

Complaints received by several enterprise operators were due to trespass onto adjoining properties and excessive engine noise. Good neighborly relations are a must for the successful

Figure 1.—The snowmobile presents several management problems for the commercial enterprise operator. Equipping rental snowmobiles with electric starters, grip bars, and inexpensive bumpers will reduce maintenance costs and add to the snowmobiler's enjoyment.

Figure 2.—A snowmobile trail through the woods. Snow cover is easier to maintain on woodland trails than on windswept open ground.

operation of a commercial snowmobile enterprise. Several operators said that community relations could be improved by giving neighbors free use of facilities. Complaints about excessive noise can result in restrictive town zoning; therefore the enterprise operator must be sure that rental snowmobiles are fitted with mufflers that meet state and local noise regulations.

Maintaining suitable trails was a problem. A home-made snowmobile trail leveler can be used to level trails after each snowfall, and to maintain trails through areas of heavy use (*Massie 1970*). Snow cover was usually adequate under tree canopies, but was difficult to maintain on windswept hilltops and over large open areas (fig. 2).

Obtaining the part-time services of a qualified snowmobile mechanic during the winter months was a problem for winter-sports areas and farm enterprise operators. The need for a mechanic was most critical during periods of heaviest demand—evening hours, weekends, and holidays—precisely the times when skilled labor is the most difficult to obtain.

Some managers attributed the destruction of vegetation to excessive use of snowmobiles. This can be a serious problem on golf courses, where fragile greens can be damaged by the concentrated weight of a snowmobile. Fragile vegetation must be protected by fences. However, a snow cover of 6 inches or more is sufficient to protect most grass surfaces from snowmobile damage (*Holyoke 1971*).

WHAT TO CONSIDER

Central New York snowmobile enterprise operators were asked what things should be considered before starting a snowmobile business. The following factors were mentioned most often.

Management Training and Experience

Nothing affects the success of a snowmobile enterprise more than the manager himself. The manager should enjoy serving the public. He must have good relations with his neighbors and community. Previous business experience or training is also important.

The potential manager should learn as much as he can about the snowmobile market and the needs of snowmobilers before he starts his business. He should determine the kind of people he wants to serve and the market clientele his business is likely to attract. He should determine what services and facilities snowmobilers want, and whether or not he can fulfill their needs. He should also consider how much they are willing to pay and should establish the potential profitability of his enterprise before opening for business. Questions about market potential can be partially answered by observing other successful snowmobile enterprises in the vicinity. The manager should subscribe to snowmobile magazines and attend meetings of local and regional snowmobile clubs. Snowmobile dealers can also provide information about the commercial snowmobile market's potential.

The potential manager should be a snowmobiler himself, and should have a first-hand impression of what snowmobil-

ers want. Such experience will also help him to understand the snowmobile's technical capabilities and requirements. Knowledge of this kind will be invaluable when the time comes to lay out trail systems and design facilities. First-hand snowmobile experience will give the potential enterprise operator the basic knowledge he needs to repair and maintain machines. However, the potential enterprise operator should not let his zeal for snowmobiling interfere with making rational business decisions.

The potential commercial snowmobile enterprise operator should be familiar with state laws that deal with snowmobiles, and the operation of commercial recreation enterprises. He should be aware of local zoning and town regulations that govern the use of snowmobiles.

Site Requirements

The commercial enterprise operators agreed that a minimum of 300 acres are required to run a profitable snowmobile business. Ideally, half of the area should be wooded to provide a scenic snowmobiling experience and to help maintain an adequate snow cover on trails. A few open flat areas were recommended, but the enterprise operators cautioned against too much wide open space. They felt that inexperienced snowmobilers tend to drive machines recklessly over wide open areas. Hilly terrain was recommended, but slopes exceeding a grade of 25 percent should be avoided to reduce machine breakdowns, decrease trail maintenance problems, and increase user safety (fig. 3).

Designated trails help to control use and ensure that the snowmobilers will not get lost, injure themselves, damage machines, or harm fragile vegetation. The trail system should be laid out to afford a variety of exposures to the natural surroundings. Interesting natural features, things of historic interest or of educational value, should be considered in laying out the trail system.

Logging roads, firebreaks, foot trails, and unplowed roads can form the basic trail system. Basic trails can be connected with a network of spur trails to provide a circular one-way

Figure 3.—Ideal snowmobile country provides hilly forested land with scattered open areas. One hazard is that inexperienced snowmobilers tend to drive too fast over open areas.

trail system. A one-way loop system, with trails 10 feet wide, provides maximum user safety. Two-way trails should be at least 15 feet wide. Tree branches overhanging trails should be removed to a vertical distance of 10 feet above average snow depth. Brush should be cleared back on both sides of the trail to a distance of 2 feet. Each user should be given a trail map that designates the degree of difficulty of each trail—novice, intermediate, or expert.

Traffic control should be considered in laying out a trail system. Signs, or a system of lights, can be used to control traffic. The trail-marking system should be similar to others used in the region. If trails are to be used at night, markers should be lighted electrically, or covered with a luminescent material. Lights are most effective for directing inexperienced snowmobilers. Yellow lights, mounted on poles, should

be located along trails to caution against excessive speed or to warn of possible danger. Flashing red lights, placed at major intersections, or wherever a complete stop is required, significantly reduce the danger of collisions. Blue lights were used by some commercial enterprise operators to designate picnic sites and other special-use areas located along or near trails.

The snowmobile enterprise may have to operate near free public snowmobile trails. Therefore the quality of commercial facilities and services must be sufficient so that the enterprise can compete with public facilities. Public snowmobile trails need not be looked upon as competition by the commercial operator. Rather, commercial snowmobile enterprises can supplement public trails by supplying facilities and services to accommodate the specialized needs of a particular clientele, such as the novice snowmobiler or the family group.

Commercial snowmobile enterprises should be located near major urban centers—where the need for commercial services and facilities is the greatest. One operator suggested that the enterprise should be located within a 1-hour driving radius of least 100,000 people.

The commercial snowmobile enterprise must be situated in a region of heavy snowfall. Several operators felt that a 10-week season, with a minimum continuous snow cover of 4 inches, would be required to break even on their investments. In regions where adequate snow cover was not consistent through the winter, operators experienced difficulty in maintaining their clientele throughout the season.

Initial Capital Investment

Initial capital investment in the eight central New York commercial snowmobile enterprises ranged from a few thousand to as much as 100,000 dollars. The initial capital investment required depended on the amount of equipment available, the amount of trail construction needed, and on how easily existing facilities could be adapted for use in the snowmobile enterprise.

The cost of developing a snowmobile trail system depends on how much trail-construction equipment is available, and on how easily existing trails and roads can be used. As previously mentioned, new trails will probably have to be constructed to connect existing trails.

A parking area of sufficient size to accommodate cars with snowmobile trailers and a snowmobile unloading ramp will have to be constructed. A snowmobile warm-up or test area should be cleared near the unloading area.

Facilities needed to establish a snowmobile enterprise may already be available. Existing farm buildings can be altered for use as warming sheds, repair shops, and sales offices (fig. 4). Most enterprise operators felt that they could not justify heavy capital investments in the construction of new build-

Figure 4.—Some facilities are needed for a snowmobile enterprise. Existing buildings can be put to use for snowmobilers.

ings and facilities. Food services should be provided. If a facility is not at hand, arrangements can usually be made with local restaurant owners to provide such a service. Flush toilets, a snowmobile repair shop, warming sheds, and a lodge were recommended as basic facilities. Enough facilities and services have to be provided to make the commercial enterprise attractive to large numbers of people.

Snowmobile enterprise operators reported that the largest capital expediture needed to establish their business was their investment in new snowmobiles. Snowmobiles range in price, depending on the model and quantity purchased. Central New York operators recommend that, to reduce maintenance and repair costs, all new machines purchased should be of the same brand.

The snowmobile enterprise operators agreed that rental of snowmobiles alone would not earn sufficient revenue to make their enterprises profitable. They suggested sales of gas and oil, repair parts, machine accessories, and maintenance service as ways of increasing revenue. Several operators also recommended the sale of snowmobiles. Providing light and easy-to-prepare winter meals was profitable for most operators.

Annual Operating Costs

Annual operating cost records were not available for the case-study enterprises. However, labor cost was mentioned as the highest single operating expense. Each enterprise has at least one full-time seasonal employee. One of the commercial winter-sports areas had a payroll of 18 full-time people. The most critical labor requirement was the need for a skilled snowmobile mechanic. In addition to hired labor, enterprise operators said that they had to devote much of their personal time to their businesses.

Machine maintenance was reported as the second highest annual operating expense. Repair parts were difficult to obtain; and breakdowns, occuring at peak use periods, made the difference between a season's profit or loss for several commercial snowmobile enterprises.

Insurance costs were high. Several operators said they had difficulty getting adequate insurance coverage, and others said that they simply could not afford insurance. However, if a landowner charges a fee for snowmobiling on his property, he assumes responsibility for the snowmobiler's safety (*Hill 1970*). Without adequate insurance coverage, the operator runs the risk of financial disaster. Each commercial snowmobile enterprise operator must determine the amount of insurance coverage he needs. One operator said that adequate insurance coverage for 10 rental snowmobiles cost him $1,500 per season. Several operators relied on limited liability statements that were signed by all persons using their trails. However, the legality of these "ride-at-your-own-risk" agreements had not been established, since they have not been tested in court.

Minor accidents were experienced at all case-study enterprises. None of these mishaps involved personal injury, but machine damage was often excessive. Only one enterprise required operators of rental machines to take out accident insurance. In this case, an insurance charge of 50¢ was added to the usual snowmobile rental fee.

The primary cause of machine damage was attributed to inexperienced drivers' running into trees (fig. 5). A significant reduction in snowmobile accidents occurred at one enterprise after a basic training course in snowmobile operation was started for novice snowmobilers. The "There's the throttle, there's the brake" training method used by most enterprise operators simply did not work.

Free training courses at two enterprises consisted of a brief discussion of the machine's operation, its capabilities, and limitations. Safe operating procedures were given heavy emphasis. Instructions were given to cover what to do in case of machine breakdown or other emergency. Finally, novice snowmobilers were allowed to practice basic maneuvers in an open field before venturing out on trails. With this minimum training effort, enterprise operators felt that they had significantly reduced machine repair costs and had added considerably to their customers' enjoyment.

Figure 5.—The commonest cause of snowmobile accidents is driving too fast. Most damage is caused by running into trees.

Enterprise operators stressed the need for adequate control and supervision of snowmobilers. Control and supervision required additional investments in specialized equipment and labor. Trail patrolmen should be trained and equipped to render first aid. Patrolmen should know how to repair snowmobiles in case of breakdowns. A system of communications is also required to report injuries and machine breakdowns. These requirements add considerably to annual operating expenses, but most enterprise operators felt that they were absolutely necessary to the long-term success of their businesses.

Market Clientele

Before starting a snowmobile enterprise, the potential operator should decide on the type of customer he can attract to his area. The facilities and services that he can offer and

the potential market clientele will determine the best type of advertising to use. Most operators expressed an interest in serving families, but several said that the family was difficult to attract because of the variety of interests within the family group. Limited success in attracting families was achieved by directing advertisements to local neighborhood and town newspapers.

Some operators tried to attract larger groups, such as snowmobile clubs, through advertisements at winter-sports shows and direct-mailing to club officers. One operator had special group rates to attract church groups and social organizations. One operator provided a free guide service, a meal, and a social program to attract groups.

Snowmobile enterprise operators said that to attract enough users to make their businesses profitable, they would have to develop special advertising programs. Free lessons, lower rate schedules on off days, women's programs, free rides for children, chili suppers, and many other advertising gimmicks were suggested.

SUMMARY & CONCLUSIONS

A commercial snowmobile business should not be started without giving careful consideration to the risks involved. The market is new, and it is difficult to estimate the profitability of commercial ventures or the size of demand for the service.

Careful study of the local market situation is necessary to evaluate the potential demand. High-quality services and facilities must be provided to make the area attractive to large numbers of people. A variety of activities should be provided if the area is to attract the diverse interests of the family group. Organized groups will also require specialized services such as meeting places and food services. Availability of nearby lodging facilities is also important.

One thing is certain: through careful planning and management, commercial enterprise can benefit from the exploding interest in snowmobiling by providing a needed serv-

ice in the right time and place. But don't go into the business just because you enjoy snowmobiling. Careful study of the market situation is needed before you jump into the business with both feet. Otherwise, you could suffer financial frostbite!

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by William C. Miller

Physical Distribution of OAK STRIP FLOORING in 1969

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FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
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DISTRIBUTION is an important aspect in the marketing of any forest product. For any marketing system to be effective, it must provide for the orderly and reliable distribution of the product, and it must provide for effective merchandising and promotion.

As an aid to the marketing of oak strip flooring, a study was made of the distribution process for this product, from manufacture to consumer—where the flooring came from, where it went, how much was shipped, and who handled it.

THE STUDY

In 1969 a mail questionnaire was developed for obtaining information for an analysis of the distribution process for the residential and commercial hardwood flooring industry in general. The information asked for included other hardwood strip flooring (except hard maple) and hardwood plank flooring.

The questionnaire was mailed on 27 January 1970, to all manufacturers (81) of residential hardwood flooring. Two subsequent mailings were made at 3-week intervals to those who did not respond to the previous mailings. Finally a follow-up telephone survey was made to contact those who still had not responded. The following response was obtained from the 81 manufacturers: 54 firms provided usable responses; 8 firms provided gross production data; 7 firms provided no gross production data; 12 firms were either not in business in 1969 or did not manufacture any residential or commercial flooring in 1969.

The data were grouped according to the regions and divisions used by the Bureau of Census (fig. 1). This grouping was used

Figure 1.—Composition of regions and geographic divisions.

to facilitate comparisons with other Government data. The "production" region as used in this report is the region in which the flooring was manufactured and from which it was shipped.

Six major channels of distribution were considered in the study: (1) builders, (2) flooring subcontractors, (3) retailers, (4) wholesalers, (5) nonstocking wholesalers, and (6) agents and brokers.

RESULTS

Responses from manufacturers to the mail questionnaire provided basic information about shipment of oak strip flooring. The shipments totaled 328,049,300 board feet. Additional information was obtained on the production of 35,143,000 board feet from those who did not respond to the mailed questionnaire. These data were combined with the questionnaire shipment data to give an adjusted total of 363,192,300 board feet, which represented about 95 percent of the total 1969 shipments of oak strip flooring.

The data presented in this paper are based solely on manufacturers' records of what happened to oak strip flooring shipments through the first step of the distribution process. What happened to the flooring after this was not examined.

PRODUCTION

Oak strip flooring is produced chiefly in the Southern and Appalachian hardwood areas of the United States.

Eighty-eight percent of the flooring was produced in the East South Central, West South Central, and South Atlantic Regions (fig. 2 and table 1). Greatest production was in the East South

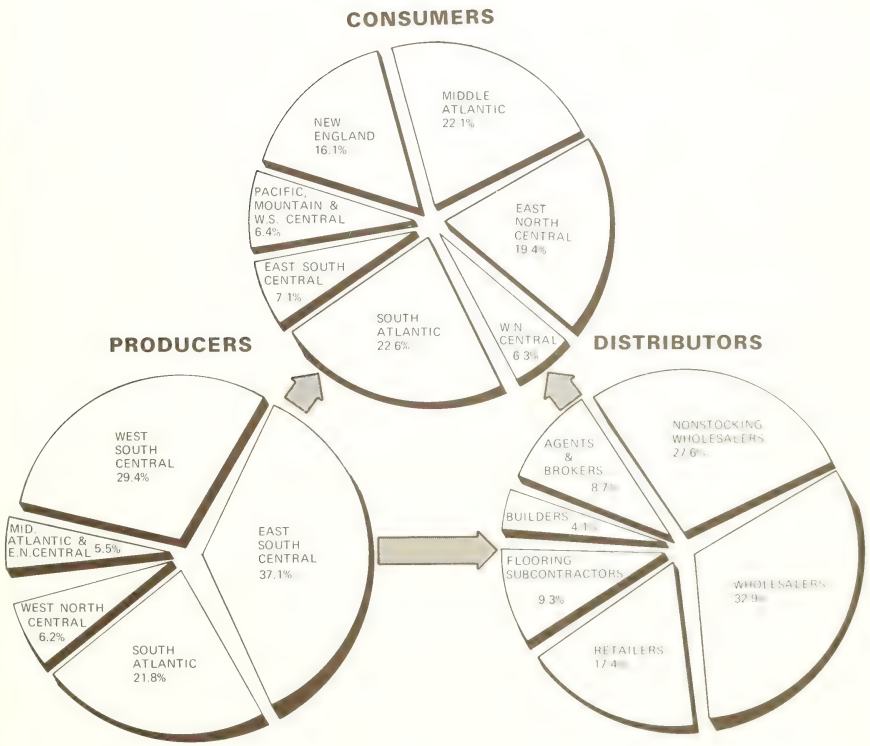

Figure 2.—Producers, consumers, and distributors of oak strip flooring in 1969.

Central Region, mainly in Tennessee and Alabama. The West South Central Region was second in production; Arkansas and Louisiana were the only producing states in this region. The South Atlantic Region was third; Virginia, Florida, and Georgia contributed the majority of the oak flooring production in that region.

Middle Atlantic and East North Central

To avoid confidential disclosure of shipment data, the data for the Middle Atlantic and East North Central production regions were combined.

Production of oak strip flooring in the Middle Atlantic and East North Central Regions accounted for about 5.5 percent (19,772,500 board feet) of the United States total (fig. 2 and table 2). Of the five regions, these regions manufactured the smallest amount of oak strip flooring.

Flooring subcontractors distributed about 56 percent of the oak strip flooring produced in these regions, and wholesalers distributed about 27 percent. Agents and brokers did not distribute any of the flooring originating in these regions.

About 29 percent of the production from the area was shipped to the West North Central and South Atlantic Regions. About 55 percent of the flooring produced stayed in the regions. A very small quantity of flooring was shipped into the West South Central Region.

West North Central

The West North Central Region produced about 6.2 percent (22,561,700 board feet) of oak strip flooring in 1969 (fig. 2 and table 2). This region ranked next to last in the production of oak flooring.

Nonstocking wholesalers were the most important distributors of flooring produced in the West North Central Region. They handled about 48 percent of the region's production. Wholesalers were the second most important distributor, handling about 32 percent of the total regional production. The majority of the

remaining flooring was handled by flooring subcontractors. Here again, as with the distribution of the Middle Atlantic and East North Central Regions' production, agents and brokers did not distribute any of the flooring produced in the West North Central Region.

About 31 percent and 26 percent, respectively, of West North Central flooring production was shipped to the East North Central and New England Regions. About 23 percent of the production stayed in the West North Central Region. A very small amount of oak strip flooring was shipped to the West South Central and Mountain Regions.

South Atlantic

About 21.8 percent (79,239,200 board feet) of the total 1969 oak strip flooring was produced in the South Atlantic Region (fig. 2 and table 2), which ranked third in production.

Agents and brokers and nonstocking wholesalers were the two most important distributors of flooring from the South Atlantic Region. They handled about 32 percent and 29 percent, respectively, of the total regional production. Retailers were third, handling about 19 percent; and builders distributed about 3 percent.

Almost 51 percent of the production was shipped to distributors in the region. The New England Region was the second largest recipient, getting about 25 percent. Less than 1 percent of the flooring produced in the South Atlantic Region was shipped to the regions west of the Mississippi River.

East South Central

The East South Central Region was the largest producer of oak strip flooring in 1969 (fig. 2 and table 2). This region accounted for about 37.1 per cent (134,771,900 board feet) of the total oak flooring production.

The flooring produced within the East South Central Region was distributed primarily through wholesalers, who handled about 49 percent of the production. Retailers and nonstocking wholesalers ranked second and third as distributors of flooring. Agents and brokers handled the least amount.

The Middle Atlantic and South Atlantic Regions each received about 23 percent of the production from the East South Central Region. The East North Central Region was the next largest recipient, getting about 19 percent of the total. About 15 percent of the production was consumed in the East South Central Region, and about 10 percent was shipped into the western half of the United States.

West South Central

The production of oak strip flooring in the West South Central Region represented about 29.4 percent (106,847,000 board feet) of the total production (fig. 2 and table 2). The region ranked second in production.

Nonstocking wholesalers, wholesalers, and retailers distributed about 89 percent of the production from the region. About 46 percent was handled by nonstocking wholesalers, and 29 percent was handled by wholesalers. Builders and agents and brokers each distributed about 3 percent.

The East North Central Region was the largest consumer of flooring produced in the West South Central Region, using about 29 percent. The Middle Atlantic and New England Regions ranked second and third in consumption, with about 25 percent and 16 percent, respectively. About 3 percent of the production was consumed in the region.

CHANNELS OF DISTRIBUTION

The distribution channels considered fall into two groups. In the first group, builders, flooring subcontractors, retailers, and wholesalers buy the flooring from the manufacturer and actually take title to it. This group handled 64 percent of the oak strip flooring.

The second group includes nonstocking wholesalers, agents, and brokers who act as marketing intermediaries. Usually, this group is paid either a percentage of the value of the flooring sold or a fixed fee per unit of flooring sold and does not take title to the flooring. About 36 percent of the flooring was sold through intermediaries.

Wholesalers handled 33 percent of the oak strip flooring produced in 1969 (fig. 2 and table 3). Nonstocking wholesalers and retailers ranked second and third.

Builders

Builders received the smallest amount of oak strip flooring from manufacturers in 1969 (fig. 2 and table 4). They handled only about 4.1 percent (14,890,900 board feet) of the total oak strip flooring production.

About 95 percent of the oak flooring distributed by builders was shipped from the East South Central, South Atlantic, and West South Central Regions. About 60 percent originated in the East South Central Region, 19 percent originated in the South Atlantic Region, and 17 percent originated in the West South Central Region. The West North Central Region supplied less than 1 percent of the flooring distributed by builders.

The Middle Atlantic Region consumed about 30 percent, the South Atlantic Region consumed 25 percent, and the East South Central Region consumed 24 percent of the total flooring distributed by builders in the Mountain and Pacific Regions.

Flooring Subcontractors

About 9.3 percent (33,776,900 board feet) of the total oak strip flooring production was distributed by flooring subcontractors (fig. 2 and table 4), who ranked fourth in volume of flooring distributed.

About 81 percent of the oak flooring distributed by flooring subcontractors originated in the Middle Atlantic and East North Central, East South Central, and West South Central Regions. About 36 percent came from the Middle Atlantic and East North Central Regions, 29 percent came from the East South Central Region, and 16 percent came from the West South Central Region. The remainder was manufactured in the South Atlantic and West North Central Regions—10 percent and 9 percent, respectively.

About one-half of the oak flooring distributed by flooring subcontractors was consumed in the Middle Atlantic and West North

Central Regions. The Middle Atlantic Region consumed about 29 percent, the East North Central Region consumed about 20 percent, and the South Atlantic Region consumed about 11 percent. A little more than 1 percent was distributed to each of the West South Central and Mountain Regions.

Retailers

Retailers ranked as the third largest type of distributor of oak strip flooring (fig. 2 and table 4), handling about 17.4 percent (63,195,400 board feet) of the total.

The East South Central Region shipped about 49 percent of the oak flooring handled by retailers, and the South Atlantic and West South Central Regions each shipped 23 to 25 percent. Retailers distributed very little flooring from either the Middle Atlantic and East North Central Regions or the West North Central Region.

Nearly 56 percent of the flooring handled by retailers was consumed in the South Atlantic Region. The East North Central and East South Central Regions each consumed about 15 percent. Less than 5 percent was consumed in the regions west of the Mississippi River.

Wholesalers

The wholesalers distributed the largest volume of oak strip flooring in 1969 (fig. 2 and table 4). They handled about 32.9 percent (119,450,300 board feet) of the total production of oak strip flooring.

About 58 percent of the flooring distributed by wholesalers was shipped from the East South Central Region, and about 24 percent was shipped from the West South Central Region. The other three regions shipped between 4 and 8 percent each.

About 29 percent of the oak strip flooring distributed by wholesalers was consumed in the Middle Atlantic Region, about 22 percent was consumed in the East North Central Region, and more than 14 percent was consumed in the New England Region. About 1 to 3 percent was consumed in the West South Central and Mountain Regions.

Nonstocking Wholesalers

Nonstocking wholesalers ranked second as distributors of oak strip flooring in 1969 (fig. 2 and table 4). They handled about 27.6 percent (100,281,100 board feet) of the oak strip flooring production.

About 46 percent of the flooring distributed by nonstocking wholesalers was manufactured in the West South Central Region. Both the South Atlantic Region and the East South Central Region provided 22 to 24 percent of the total, respectively. Less than 1 percent of the flooring was provided by the Middle Atlantic and East North Central Regions.

The Middle Atlantic, East North Central, South Atlantic, and New England Regions consumed about 88 percent of the oak strip flooring distributed by nonstocking wholesalers. About 24 percent was consumed in the Middle Atlantic Region; 22 to 23 percent was consumed in the East North Central Region and the South Atlantic Region. Less than 10 percent was consumed in the regions west of the Mississippi River.

Agents and Brokers

Agents and brokers distributed about 8.7 percent (31,597,700 board feet) of the total oak strip flooring production. Agents and brokers ranked next to last as distributors of flooring (fig. 2 and table 4).

The South Atlantic Region produced about 82 percent of the flooring distributed by agents and brokers. The other 18 percent was produced in the East South Central and West South Central Regions.

About 53 percent of the flooring distributed by agents and brokers was consumed in the New England Region, about 18 percent was consumed in the South Atlantic Region, and about 11 percent was consumed in the Middle Atlantic Region. Only 2 to 3 percent was consumed in the regions in the western half of the United States.

CONSUMPTION

In the past, the eastern half of the United States has consumed the greatest volume of oak strip flooring because of the joist-type of residential construction used in the area. More than 87 percent of the oak strip flooring shipments (fig. 2 and table 5) was consumed east of the Mississippi River. The South Atlantic, Middle Atlantic, East North Central, and New England Regions consumed about 80 percent of that total. A relatively small amount of flooring was consumed in each of the other regions.

New England

Consumption in the New England Region was about 16.1 percent—58,474,000 board feet (fig. 2 and table 6) of the total United States consumption of oak strip flooring.

About 35 percent of the flooring consumed was shipped from the South Atlantic Region. The majority of the remaining shipments into New England came from the East South Central and West South Central Regions.

Nonstocking wholesalers distributed about 34 percent of the total flooring consumed in New England, and wholesalers distributed about 30 percent. Only a little over 1 percent of the flooring was distributed by flooring subcontractors.

Middle Atlantic

Consumption of oak strip flooring in the Middle Atlantic Region represented 22.1 percent of the total United States consumption—80,265,500 board feet (fig. 2 and table 6). About 40 percent of this flooring was shipped from the East South Central Region. Another 46 percent was shipped from the South Atlantic and West South Central Regions.

About 81 percent of the shipments from Middle Atlantic and East South Central Regions was distributed by flooring subcontractors (table 6). Agents and brokers were almost as important as wholesalers and nonstocking wholesalers in the handling of shipments from the South Atlantic Region. However, for the region as a whole, wholesalers distributed about 43 per-

cent of the flooring consumed in the region, and nonstocking wholesalers distributed about 30 percent, thereby making these two categories of distributors dominant in the region.

East North Central

About 89 percent of the 70,459,300 board feet (about 19.4 percent of the total United States consumption) of the oak strip flooring consumed in the East North Central Region was shipped from the South Atlantic, East South Central and West South Central Regions (fig. 2 and table 6).

Agents and brokers were the most important distributors of shipments from the South Atlantic Region, whereas the nonstocking wholesalers were most important in the handling of shipments from the West North Central Region (table 6). Builders, on the other hand, distributed the least volume. However, for the region as a whole, about 38 percent of the shipments into the region were distributed by wholesalers, thereby making them the dominant distributors in the region.

West North Central

The West North Central Region consumed 6.3 percent (22,881,100 board feet) of the total United States consumption of oak strip flooring (fig. 2 and table 6). About 60 percent of this total was shipped from the East South Central and West South Central Regions.

Flooring subcontractors distributed about 37 percent of the flooring sold in the region, and wholesalers distributed about 30 percent.

The nonstocking wholesalers distributed about 50 percent of the flooring produced in the region (table 6). Ninety percent of the flooring shipped from the South Atlantic Region into the West North Central Region was distributed by nonstocking wholesalers.

South Atlantic

The South Atlantic Region is very large, including the metropolitan areas of Miami, Atlanta, Baltimore, and Washington.

The region was not only one of the three major oak strip

flooring producing regions, but it also consumed about 22.6 percent (82,081,500 board feet) of the total oak strip flooring consumed in the United States in 1969 (fig. 2 and table 6).

More than 49 percent of the flooring consumed in the South Atlantic Region was produced in the region. The East South Central and West South Central Regions produced the majority of the remaining flooring consumed in the South Atlantic Region.

Retailers distributed about 42 percent of the flooring consumed in the South Atlantic Region. This region constitutes a well-established traditional market for oak strip flooring. Nonstocking wholesalers distributed about 27 percent of the flooring consumed in the region.

East South Central

The East South Central Region produced about 37 percent of the total oak strip flooring but consumed only about 7.1 percent (25,786,600 board feet) of the total (fig. 2 and table 6). About 82 percent of the flooring consumed in the East South Central Region was manufactured within the region.

Retailers distributed about 36 percent of the flooring consumed, and wholesalers ranked second as distributors of consumed flooring. Agents and brokers were the most important distributors for shipments from both the South Atlantic and West South Central Regions, whereas nonstocking wholesalers were most important in handling shipments from the West North Central Region (table 6).

This region is similar to the South Atlantic and West South Central Regions because there is a well-established traditional market for oak strip flooring in the East South Central Region.

West South Central

The 1969 demand for oak strip flooring in the West South Central Region was relatively small, about 1.4 percent of the total United States consumption—5,084,700 board feet (fig. 2 and table 6). The West South Central Region produced 70 percent of the flooring consumed in the region.

Retailers distributed nearly 39 percent of the flooring con-

sumed in this region, and nonstocking wholesalers distributed about 26 percent. The minute amount of flooring shipped from the West North Central Region was handled exclusively by builders, and no flooring was shipped from the South Atlantic Region (table 6).

Mountain

About 63 percent of the small amount (about 1.2 percent of total United States consumption or 4,358,300 board feet) of oak strip flooring sold in the Mountain Region was shipped from the West South Central Region (fig. 2 and table 6). Most of the remaining flooring was shipped from the East South Central, Middle Atlantic, and East North Central Regions. No flooring came in from the South Atlantic Region.

As with most of the other regions, wholesalers were dominant in distributing flooring. They handled about 58 percent of it. Flooring subcontractors handled the small volume of flooring originating in the West North Central Region (table 6). No flooring was handled by builders or agents and brokers in the region.

Pacific

About 3.8 percent of the total oak strip flooring produced in the United States (13,801,300 board feet) was consumed in the Pacific Region (fig. 2 and table 6). About 90 percent of the flooring was produced in the East and West South Central Regions. Wholesalers handled 74 percent of the flooring shipped into the region. Flooring subcontractors and nonstocking wholesalers handled the majority of the remaining flooring (about 25 percent). The consumption in this region is relatively small considering the fact that there are several very large metropolitan areas in the region.

Total United States

The South Atlantic, East South Central, and West South Central Regions shipped about 22, 37, and 29 percent, respectively, of the total United States consumption of 363,192,300 board feet of oak strip flooring in 1969 (fig. 2 and table 6).

Wholesalers, nonstocking wholesalers, and retailers were the three most important distributors. They handled 33, 28, and 17 percent, respectively, of the total United States consumption. Builders were the least active distributors.

On a regional basis, flooring subcontractors were used extensively in the distribution of flooring shipped from the Middle Atlantic and East North Central Regions whereas agents, brokers, and nonstocking wholesalers were used extensively in handling shipments from the South Atlantic Region (table 6).

DISCUSSION AND SUMMARY

Information provided by hardwood flooring manufacturers was used to determine the physical distribution patterns existing in the oak strip flooring industry in 1969.

The conclusions are based on shipment of 363,192,300 board feet. This represents approximately 95 percent of the total volume shipped in 1969.

Most of the production of oak strip flooring is in the Southern and Appalachian hardwood forest areas of the United States. The South Atlantic, East South Central, and West South Central Regions of the United States produced 88 per cent of the oak strip flooring sold in the United States in 1969. The Middle Atlantic, East North Central, and West North Central Regions produced the remainder.

The production-consumption relationship varies greatly from region to region. The consumption within the South Atlantic Region was about 51 percent of the production in the region. The consumption in the East South Central and West South Central Regions was about 15 and 3 percent, respectively, of the production in those regions.

The Middle Atlantic and East North Central composite region consumed over 53 percent of the production in the region. The West North Central Region consumed only 23 percent of its production.

Total consumption of oak flooring also varied considerably from region to region throughout the United States. Most of

the consumption was in the New England, Middle Atlantic, East North Central, and South Atlantic Regions. The highest consumption was in the South Atlantic Region, which accounted for about 23 percent of the total United States consumption. It was followed closely by the Middle Atlantic Region, which consumed 22 percent of the total.

In contrast, the West South Central and Mountain Regions accounted for only a little more than 2 percent of the total consumption. Generally speaking, the dividing line in the concentration of oak strip flooring markets is the Mississippi River—about 90 percent of the markets are found to the East, and about 10 percent are found to the West.

Wholesalers were the main distributors of flooring throughout the United States. They handled about 33 percent of all oak strip flooring shipped in 1969. Nonstocking wholesalers ranked second as distributors of flooring, and retailers ranked third. Builders were the least used type of distributors, indicating that few of them buy directly from the manufacturer.

Even though wholesalers dominated the distribution patterns in most regions, retailers handled most of the shipments into the three largest producing regions—South Atlantic, East South Central, and West South Central.

APPENDIX

Table 1.—*1969 production of oak strip flooring,*[1] *by geographic region*

Geographic region	Production	Percent of U. S. total
	MBF	*Percent*
Middle Atlantic & East North Central[2]	19,772.5	5.5
West North Central	22,561.7	6.2
South Atlantic	79,239.2	21.8
East South Central	134,771.9	37.1
West South Central	106,847.0	29.4
U. S. total	363,192.3	100.0

[1]Figures reflect a small amount of plank flooring and include other hardwood strip and plank flooring (except hard maple).

[2]To avoid confidential disclosure of production data, data for the Middle Atlantic and East North Central production regions were combined.

Table 2.—*Production of oak strip flooring[1] in 1969, in percent*

Shipped to—	Kind of distributor						Percent total	Percent of—	
	Builders	Flooring subcontractors	Retailers	Wholesalers	Non-stocking wholesalers	Agents & brokers		Production region total	U.S. total
MIDDLE ATLANTIC & EAST NORTH CENTRAL REGIONS[2]									
New England	44.5	2.8	—	52.7	—	—	100.0	5.5	0.3
Middle Atlantic	1.4	81.4	0.7	16.1	0.4	—	100.0	41.8	2.3
East North Central	—	36.0	10.7	43.9	9.4	—	100.0	12.7	.7
West North Central	—	61.0	4.7	34.3	—	—	100.0	21.8	1.2
South Atlantic	—	—	80.0	—	20.0	—	100.0	7.3	.4
East South Central	10.0	20.0	65.0	5.0	—	—	100.0	1.8	.1
West South Central	10.0	10.0	50.0	30.0	—	—	100.0	([3])	([3])
Mountain	—	—	.7	99.3	—	—	100.0	3.6	.2
Pacific	—	76.7	—	23.3	—	—	100.0	5.5	.3
Entire U.S., percent	3.4	56.1	10.3	27.2	3.0	—	100.0	100.0	5.5
Production total (MBF)	—	—	—	—	—	—	—	19,772.5	363,192.3
WEST NORTH CENTRAL REGION									
New England	—	—	—	39.1	60.9	—	100.0	25.8	1.6
Middle Atlantic	—	—	—	61.9	38.1	—	100.0	12.9	.8
East North Central	—	21.4	0.9	37.6	40.1	—	100.0	30.7	1.9
West North Central	—	41.0	3.1	6.4	49.5	—	100.0	22.6	1.3
South Atlantic	—	—	—	28.6	71.4	—	100.0	3.2	.2
East South Central	—	—	—	—	100.0	—	100.0	3.2	.3
West South Central	100.0	—	—	—	—	—	100.0	([3])	([3])
Mountain	—	100.0	—	—	—	—	100.0	([3])	([3])
Pacific	—	73.0	—	27.0	—	—	100.0	1.6	.1
Entire U.S., percent	0.1	18.8	1.0	32.4	47.7	—	100.0	100.0	6.2
Production total (MBF)	—	—	—	—	—	—	—	22,561.7	363,192.3

SOUTH ATLANTIC REGION									
New England	—	—	—	2.8	17.1	80.1	100.0	24.8	5.4
Middle Atlantic	1.3	3.3	13.5	23.9	32.6	25.4	100.0	15.6	3.4
East North Central	—	—	21.7	4.7	30.4	43.2	100.0	6.4	1.4
West North Central	—	—	—	10.0	90.0	—	100.0	.5	.1
South Atlantic	6.3	6.9	30.2	14.9	33.8	7.9	100.0	50.9	11.1
East South Central	—	—	2.3	—	5.5	92.2	100.0	1.4	.3
West South Central	—	—	—	—	—	—	—	—	—
Mountain	—	—	—	—	—	—	—	—	—
Pacific	—	—	—	10.0	90.0	—	100.0	.4	.1
Entire U.S., percent	3.4	4.1	18.9	12.4	29.1	32.1	100.0	100.0	21.8
Production total (MBF)	—	—	—	—	—	—	—	79,239.2	363,192.3
EAST SOUTH CENTRAL REGION									
New England	5.1	4.3	4.2	62.0	21.9	2.5	100.0	11.1	4.1
Middle Atlantic	8.2	5.6	2.7	65.6	16.7	1.2	100.0	22.6	8.4
East North Central	2.4	7.8	6.9	59.9	22.3	.7	100.0	18.6	6.9
West North Central	—	35.9	2.6	44.5	14.2	2.8	100.0	4.6	1.7
South Atlantic	3.1	2.6	54.6	21.0	15.0	3.7	100.0	22.6	8.4
East South Central	16.7	7.4	39.6	29.1	6.2	1.0	100.0	15.1	5.6
West South Central	8.6	9.0	49.4	29.8	2.3	.9	100.0	1.1	.4
Mountain	—	—	4.7	91.8	3.5	—	100.0	.5	.2
Pacific	—	.9	—	96.7	2.4	—	100.0	3.8	1.4
Entire U.S., percent	6.2	6.7	21.3	48.5	15.5	1.8	100.0	100.0	37.1
Production total (MBF)	—	—	—	—	—	—	—	134,771.9	363,192.3

CONTINUED

Table 2.—Continued

Shipped to—	Kind of distributor						Percent total	Percent of—	
	Builders	Flooring subcontractors	Retailers	Wholesalers	Non-stocking wholesalers	Agents & brokers		Production region total	U.S. total
WEST SOUTH CENTRAL REGION									
New England	—	0.4	7.3	28.5	63.8	—	100.0	16.0	4.7
Middle Atlantic	6.2	—	5.5	32.8	55.5	—	100.0	24.5	7.2
East North Central	.5	8.4	22.2	24.1	44.8	—	100.0	28.9	8.5
West North Central	9.2	18.7	4.8	26.2	31.5	9.6	100.0	6.5	1.9
South Atlantic	—	.6	41.0	10.2	34.2	14.0	100.0	8.5	2.5
East South Central	2.8	5.5	22.7	8.6	16.5	43.9	100.0	3.0	.9
West South Central	.7	9.2	34.2	19.0	36.9	—	100.0	3.4	1.0
Mountain	—	10.6	.3	39.9	49.2	—	100.0	2.7	.8
Pacific	2.5	14.2	—	67.7	15.6	—	100.0	6.5	1.9
Entire U.S., percent	2.5	5.4	14.7	28.5	45.9	3.0	100.0	100.0	29.4
Production total (MBF)	—	—	—	—	—	—	—	106,847.0	363,192.3
ALL REGIONS									
New England	2.3	1.4	3.2	30.0	34.1	29.0	100.0	—	16.1
Middle Atlantic	5.5	12.0	5.0	43.4	29.7	4.4	100.0	—	22.1
East North Central	1.1	9.6	14.3	38.4	33.1	3.5	100.0	—	19.4
West North Central	2.7	36.8	3.8	29.8	23.2	3.7	100.0	—	6.3
South Atlantic	4.3	4.5	41.5	16.5	26.5	6.7	100.0	—	22.6
East South Central	14.2	7.0	36.1	24.9	8.2	9.6	100.0	—	7.1
West South Central	3.5	9.1	38.6	22.2	26.4	.2	100.0	—	1.4
Mountain	—	9.2	1.2	57.5	32.1	—	100.0	—	1.2
Pacific	1.3	14.7	—	74.0	10.0	—	100.0	—	3.8

Entire U.S., percent	4.1	9.3	17.4	32.9	27.6	8.7	100.0	—	100.0
Production total (MBF)	—	—	—	—	—	—	—	—	363,192.3

[1]Figures reflect a small amount of plank flooring and include other hardwood strip and plank floorings (except hard maple).
[2]To avoid confidential disclosure of shipment data, Middle Atlantic and East North Central production regions were combined.
[3]Less than 0.05 percent.

Table 3.—*Volume of oak strip flooring*[1] *production handled by major distributors*

Distributor	Production	Percent of U. S. total
	MBF	*Percent*
Builders	14,890.9	4.1
Flooring subcontractors	33,776.9	9.3
Retailers	63,195.4	17.4
Wholesalers	119,450.3	32.9
Nonstocking wholesalers	100,281.1	27.6
Agents & brokers	31,597.7	8.7
U. S. total	363,192.3	100.0

[1]Figures reflect a small amount of plank flooring and include other hardwood strip and plank floorings (except hard maple).

Shipped to—	Production by geographic region					Percent total	Percent of—	
	Middle Atlantic & East North Central[2]	West North Central	South Atlantic	East South Central	West South Central		Distribution total	U. S. total
BUILDERS								
New England	40.6	—	—	59.4	—	100.0	9.1	0.3
Middle Atlantic	2.9	—	3.8	59.2	34.1	100.0	30.0	1.2
East North Central	—	—	—	82.7	17.3	100.0	5.2	.2
West North Central	—	—	—	—	100.0	100.0	4.0	.2
South Atlantic	—	—	72.0	28.0	—	100.0	24.2	1.0
East South Central	1.0	—	—	97.0	2.0	100.0	25.2	1.0
West South Central	7.4	11.2	—	66.7	14.7	100.0	1.2	.1
Mountain	—	—	—	—	—	—	—	—
Pacific	—	—	—	—	100.0	100.0	1.1	.1
Entire U. S., percent	4.9	0.1	18.6	59.5	16.9	100.0	100.0	4.1
Distribution total (MBF)	—	—	—	—	—	—	14,890.9	363,192.3
FLOORING SUBCONTRACTORS								
New England	4.3	—	—	87.0	8.7	100.0	2.4	0.2
Middle Atlantic	76.9	—	4.3	18.8	—	100.0	28.9	2.7
East North Central	16.0	15.3	—	31.9	36.8	100.0	19.6	1.8
West North Central	36.0	19.6	—	29.4	15.0	100.0	24.5	2.3
South Atlantic	—	—	76.0	22.5	1.5	100.0	10.7	1.0
East South Central	4.1	—	—	87.6	8.3	100.0	5.5	.5
West South Central	2.8	—	—	26.8	70.4	100.0	1.4	.1
Mountain	—	26.7	—	—	73.3	100.0	1.2	.1
Pacific	35.9	15.2	—	2.5	46.4	100.0	5.8	.6
Entire U. S., percent	36.4	8.9	9.8	28.6	16.3	100.0	100.0	9.3
Distribution total (MBF)	—	—	—	—	—	—	33,776.9	363,192.3

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Table 4.—Continued

Shipped to—	Production by geographic region					Percent of—		
	Middle Atlantic & East North Central[2]	West North Central	South Atlantic	East South Central	West South Central	Percent total	Distribution total	U. S. total
RETAILERS								
New England	—	—	—	36.2	63.8	100.0	2.9	0.5
Middle Atlantic	1.6	—	42.6	21.9	33.9	100.0	6.4	1.1
East North Central	3.2	0.4	11.5	19.0	65.9	100.0	16.0	2.8
West North Central	27.1	14.6	—	20.5	37.8	100.0	1.3	.2
South Atlantic	3.8	—	35.7	50.4	10.1	100.0	55.0	9.6
East South Central	2.6	—	.3	90.5	6.6	100.0	15.1	2.6
West South Central	3.3	—	—	34.7	62.0	100.0	3.2	.6
Mountain	8.4	—	—	74.9	16.7	100.0	.1	([3])
Pacific	—	—	—	—	—	—	—	—
Entire U. S., percent	3.5	0.3	24.4	48.5	23.3	100.0	100.0	17.4
Distribution total (MBF)	—	—	—	—	—	—	63,195.4	363,192.3
WHOLESALERS								
New England	3.8	9.3	3.3	57.3	26.3	100.0	14.8	4.9
Middle Atlantic	4.2	3.8	8.6	60.3	23.1	100.0	29.1	9.6
East North Central	4.9	6.7	.9	61.0	26.5	100.0	22.7	7.5
West North Central	25.0	3.8	.3	44.9	26.0	100.0	5.7	1.9
South Atlantic	—	.5	44.3	48.8	6.4	100.0	11.3	3.7
East South Central	.3	—	—	96.1	3.6	100.0	5.3	1.7
West South Central	3.5	—	—	36.5	60.0	100.0	.7	.2
Mountain	24.7	—	—	31.0	44.3	100.0	2.2	.7
Pacific	2.2	1.1	.2	52.4	44.1	100.0	8.2	2.7
Entire U. S., percent	5.0	4.3	8.4	58.3	24.0	100.0	100.0	32.9
Distribution total (MBF)	—	—	—	—	—	—	119,450.3	363,192.3

NONSTOCKING WHOLESALERS								
New England	—	12.7	17.7	17.8	51.8	100.0	19.9	5.5
Middle Atlantic	.2	3.4	17.2	22.3	56.9	100.0	23.7	6.5
East North Central	1.2	8.3	6.9	26.3	57.3	100.0	23.2	6.4
West North Central	—	37.5	3.9	18.5	40.1	100.0	5.4	1.5
South Atlantic	1.5	.8	62.6	21.8	13.3	100.0	21.5	5.9
East South Central	—	12.8	3.1	62.9	21.2	100.0	2.2	.6
West South Central	—	—	—	2.4	97.6	100.0	1.4	.4
Mountain	—	—	—	2.1	97.9	100.0	1.4	.4
Pacific	—	—	14.9	9.8	75.3	100.0	1.3	.4
Entire U. S., percent	0.6	7.6	23.6	22.1	46.1	100.0	100.0	27.6
Distribution total (MBF)	—	—	—	—	—	—	100,281.1	363,192.3
AGENTS AND BROKERS								
New England	—	—	97.6	3.4	—	100.0	54.1	4.7
Middle Atlantic	—	—	89.6	10.4	—	100.0	11.4	1.0
East North Central	—	—	92.3	7.7	—	100.0	7.6	.7
West North Central	—	—	—	23.3	76.7	100.0	2.5	.2
South Atlantic	—	—	57.5	21.0	21.5	100.0	16.4	1.4
East South Central	—	—	43.4	8.8	47.8	100.0	8.0	.7
West South Central	—	—	—	100.0	—	100.0	([3])	([3])
Mountain	—	—	—	—	—	—	—	—
Pacific	—	—	—	—	—	—	—	—
Entire U. S., percent	—	—	82.3	8.1	9.6	100.0	100.0	8.7
Distribution total (MBF)	—	—	—	—	—	—	31,597.7	363,192.3

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Table 4.—Continued

Shipped to—	Production by geographic region					Percent total	Percent of—	
	Middle Atlantic & East North Central[2]	West North Central	South Atlantic	East South Central	West South Central		Distribution total	U. S. total
				ALL DISTRIBUTORS				
New England	2.1	7.1	35.3	27.7	27.8	100.0	—	16.1
Middle Atlantic	11.3	2.7	15.7	39.8	30.5	100.0	—	22.1
East North Central	4.2	6.9	7.5	39.1	42.3	100.0	—	19.4
West North Central	21.7	17.6	1.0	30.1	29.6	100.0	—	6.3
South Atlantic	1.9	.3	49.1	38.4	10.3	100.0	—	22.6
East South Central	1.4	1.1	4.5	82.5	10.5	100.0	—	7.1
West South Central	2.6	.4	—	27.0	70.0	100.0	—	1.4
Mountain	14.3	2.5	—	19.4	63.8	100.0	—	1.2
Pacific	6.9	3.1	1.7	40.1	48.2	100.0	—	3.8
Entire U. S., percent	5.5	6.2	21.8	37.1	29.4	100.0	—	100.0
Distribution total (MBF)	—	—	—	—	—	—	—	363,192.3

[1]Figures reflect a small amount of plank flooring and include other hardwood strip and plank floorings (except hard maple).
[2]In order to avoid confidential disclosure of shipment data, Middle Atlantic and East North Central production regions were combined.
[3]Less than 0.05 percent.

Table 5.—*1969 consumption of oak strip flooring*[1] *by location*

Shipped to—	Consumption	Percent of U. S. total
	MBF	*Percent*
New England	58,474.0	16.1
Middle Atlantic	80,265.5	22.1
East North Central	70,459.3	19.4
West North Central	22,881.1	6.3
South Atlantic	82,081.5	22.6
East South Central	25,786.6	7.1
West South Central	5,084.7	1.4
Mountain	4,358.3	1.2
Pacific	13,801.3	3.8
U. S. total	363,192.3	100.0

[1]Figures reflect a small amount of plank flooring and include other hardwood strip and plank floorings (except hard maple).

Table 6.—*Consumption of oak strip flooring[1] in 1969, in percent*

Shipped to—	Kind of distributor						Percent total	Percent of—	
	Builders	Flooring sub-contractors	Retailers	Wholesalers	Non-stocking wholesalers	Agents & brokers		Production region total	U. S. total
NEW ENGLAND REGION									
Middle Atlantic & East North Central[2]	44.5	2.8	—	52.7	—	—	100.0	2.1	0.3
West North Central	—	—	—	39.1	60.9	—	100.0	7.1	1.6
South Atlantic	—	—	—	2.8	17.1	80.1	100.0	35.3	5.4
East South Central	5.1	4.3	4.2	62.0	21.9	2.5	100.0	27.7	4.1
West South Central	—	.4	7.3	28.5	63.8	—	100.0	27.8	4.7
Percent total	2.3	1.4	3.2	30.0	34.1	29.0	100.0	100.0	16.1
Consumption total (MBF)	—	—	—	—	—	—	—	58,474.0	363,192.3
MIDDLE ATLANTIC REGION									
Middle Atlantic & East North Central[2]	1.4	81.4	0.7	16.1	0.4	—	100.0	11.3	2.3
West North Central	—	—	—	61.9	38.1	—	100.0	2.7	.8
South Atlantic	1.3	3.3	13.5	23.9	32.6	25.4	100.0	15.7	3.4
East South Central	8.2	5.6	2.7	65.6	16.7	1.2	100.0	39.8	8.4
West South Central	6.2	—	5.5	32.8	55.5	—	100.0	30.5	7.2
Percent total	5.5	12.0	5.0	43.4	29.7	4.4	100.0	100.0	22.1
Consumption total (MBF)	—	—	—	—	—	—	—	80,265.5	363,192.3

EAST NORTH CENTRAL REGION									
Middle Atlantic & East North Central[2]	—	36.0	10.7	43.9	9.4	—	100.0	4.2	0.7
West North Central	—	21.4	.9	37.6	40.1	—	100.0	6.9	1.9
South Atlantic	—	—	21.7	4.7	30.4	43.2	100.0	7.5	1.4
East South Central	2.4	7.8	6.9	59.9	22.3	.7	100.0	39.1	6.9
West South Central	.5	8.4	22.2	24.1	44.8	—	100.0	42.3	8.5
Percent total	1.1	9.6	14.3	38.4	33.1	3.5	100.0	100.0	19.4
Consumption total (MBF)	—	—	—	—	—	—	—	70,459.3	363,192.3
WEST NORTH CENTRAL REGION									
Middle Atlantic & East North Central[2]	—	61.0	4.7	34.3	—	—	100.0	21.7	1.2
West North Central	—	41.0	3.1	6.4	49.5	—	100.0	17.6	1.4
South Atlantic	—	—	—	10.0	90.0	—	100.0	1.0	0.1
East South Central	—	35.9	2.6	44.5	14.2	2.8	100.0	30.1	1.7
West South Central	9.2	18.7	4.8	26.2	31.5	9.6	100.0	29.6	1.9
Percent total	2.7	36.8	3.8	29.8	23.2	3.7	100.0	100.0	6.3
Consumption total (MBF)	—	—	—	—	—	—	—	22,881.1	363,192.3
SOUTH ATLANTIC REGION									
Middle Atlantic & East North Central[2]	—	—	80.0	—	20.0	—	100.0	1.9	0.4
West North Central	—	—	—	28.6	71.4	—	100.0	.3	.2
South Atlantic	6.3	6.9	30.2	14.9	33.8	7.9	100.0	49.1	11.1
East South Central	3.1	2.6	54.6	21.0	15.0	3.7	100.0	38.4	8.4
West South Central	—	.6	41.0	10.2	34.2	14.0	100.0	10.3	2.5
Percent total	4.3	4.5	41.5	16.5	26.5	6.7	100.0	100.0	22.6
Consumption total (MBF)	—	—	—	—	—	—	—	82,081.5	363,192.3

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Table 6.—Continued

Shipped to—	Kind of distributor						Percent total	Percent of—	
	Builders	Flooring sub-contractors	Retailers	Wholesalers	Non-stocking wholesalers	Agents & brokers		Production region total	U. S. total
EAST SOUTH CENTRAL REGION									
Middle Atlantic & East North Central[2]	10.0	20.0	65.0	5.0	—	—	100.0	1.4	0.1
West North Central	—	—	—	—	100.0	—	100.0	1.1	.2
South Atlantic	—	—	2.3	—	5.5	92.2	100.0	4.5	.3
East South Central	16.7	7.4	39.6	29.1	6.2	1.0	100.0	82.5	5.6
West South Central	2.8	5.5	22.7	8.6	16.5	43.9	100.0	10.5	.9
Percent total	14.2	7.0	36.1	24.9	8.2	9.6	100.0	100.0	7.1
Consumption total (MBF)	—	—	—	—	—	—	—	25,786.6	363,192.3
WEST SOUTH CENTRAL REGION									
Middle Atlantic & East North Central[2]	10.0	10.0	50.0	30.0	—	—	100.0	2.6	([3])
West North Central	100.0	—	—	—	—	—	100.0	.4	([3])
South Atlantic	—	—	—	—	—	—	—	—	—
East South Central	8.6	9.0	49.4	29.8	2.3	0.9	100.0	27.0	.4
West South Central	.7	9.2	34.2	19.0	36.9	—	100.0	70.0	1.0
Percent total	3.5	9.1	38.6	22.2	26.4	0.2	100.0	100.0	1.4
Consumption total (MBF)	—	—	—	—	—	—	—	5,084.7	363,192.3
MOUNTAIN REGION									
Middle Atlantic & East North Central[2]	—	—	0.7	99.3	—	—	100.0	14.3	0.2
West North Central	—	100.0	—	—	—	—	100.0	2.5	([3])

South Atlantic	—	—	—	—	—	—	—	—	—
East South Central	—	—	4.7	91.8	3.5	—	100.0	19.4	.2
West South Central	—	10.6	.3	39.9	49.2	—	100.0	63.8	.8
Percent total	—	9.2	1.2	57.5	32.1	—	100.0	100.0	1.2
Consumption total (MBF)	—	—	—	—	—	—	—	4,358.3	363,192.3
PACIFIC REGION									
Middle Atlantic & East North Central[2]	—	76.7	—	23.3	—	—	100.0	6.9	0.3
West North Central	—	73.0	—	27.0	—	—	100.0	3.1	.1
South Atlantic	—	—	—	10.0	90.0	—	100.0	1.7	.1
East South Central	—	.9	—	96.7	2.4	—	100.0	40.1	1.4
West South Central	2.5	14.2	—	67.7	15.6	—	100.0	48.2	1.9
Percent total	1.3	14.7	—	74.0	10.0	—	100.0	100.0	3.8
Consumption total (MBF)	—	—	—	—	—	—	—	13,801.3	363,192.3
TOTAL UNITED STATES									
Middle Atlantic & East North Central[2]	3.4	56.1	10.3	27.2	3.0	—	100.0	—	5.5
West North Central	.1	18.8	1.0	32.4	47.7	—	100.0	—	6.2
South Atlantic	3.4	4.1	18.9	12.4	29.1	32.1	100.0	—	21.8
East South Central	6.2	6.7	21.3	48.5	15.5	1.8	100.0	—	37.1
West South Central	2.5	5.4	14.7	28.5	45.9	3.0	100.0	—	29.4
Percent total	4.1	9.3	17.4	32.9	27.6	8.7	100.0	—	100.0
Consumption total (MBF)	—	—	—	—	—	—	—	—	363,192.3

[1]Figures reflect a small amount of plank flooring and include other hardwood strip and plank floorings (except hard maple).
[2]In order to avoid confidential disclosure of shipment data, Middle Atlantic and East North Central production regions were combined.
[3]Less than 0.05 percent.

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